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Cigarette Ignition of Soft Furnishings— a Literature Review With Commentary

Technical
Study Group
Cigarette Safety
Act of 1984

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June 1987

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Fire Research
National Bureau
of Standards

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Mission and Members

The Technical Study Group on Cigarette and Little Cigar Fire Safety was established by Public Law 98-567, the Cigarette Safety Act of 1984, on October 30, 1984. Its mission is to:

"undertake such studies and other activities as it considers necessary and appropriate to determine the technical and commercial feasibility, economic impact, and other consequences of developing cigarettes and little cigars that will have a minimum propensity to ignite upholstered furniture or mattresses. Such activities include identification of the different physical characteristics of cigarettes and little cigars which have an impact on the ignition of upholstered furniture and mattresses, an analysis of the feasibility of altering any pertinent characteristics to reduce ignition propensity, and an analysis of the possible costs and benefits, both to the industry and the public, associated with any such product modification."

Copies of this or any other reports of the Technical Study Group may be obtained from Mr. Colin B. Church, Secretariat, Technical Study Group, Consumer Product Safety Commission, 5401 Westbard Avenue, Washington, D.C., 20207.

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Abstract

Literature pertinent to the ignition by smoldering cigarettes of upholstered furniture and mattresses (soft furnishings) was searched through early 1986. This included literature on the smoldering behavior of cigarettes in air; their behavior on a variety of substrates simulating soft furnishings; mechanism of smoldering in substrates; relative cigarette ignition resistance of substrates; and relative propensity of commercial cigarette packings to ignite substrates.

According to the reviewed literature, the smoldering behavior of cigarettes on substrates differs from that of cigarettes burning in air: on substrates, cigarette temperatures tend to be *lower*, and burning rates *slower*. These differences seem to be larger for substrates which ignite than for those which self-extinguish after the cigarette burns out. The characteristics of soft furnishings which insure resistance to cigarette ignition have been established, but those of cigarettes with low propensity to ignite furnishings have not. No mathematical model has been reported for the interaction of cigarette and substrate, but some empirical data do exist.

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Introduction

This literature survey was undertaken as part of the overall program mandated by the Cigarette Safety Act of 1984 [1]. The Act seeks a reduction in the losses from fires caused by cigarettes inadvertently dropped on mattresses or upholstered furniture (soft furnishing substrates[1] by modifying the ignition[2] propensity of the cigarette. The 1984 estimates for cigarette-caused fire incidents in residences are as follows: 49,000 structural fires (7.9 percent of total), 1530 civilian deaths, 3950 civilian injuries, and 320 million dollars property loss (36, 19, and 9.3 percent of total, respectively) [2,3]. While the number of cigarette-caused fires have decreased over the last few years, they still represent the largest single cause of residential fire death.

About 600 billion cigarettes are presently consumed in the U.S. annually [4]; this means that only about one in 12 million cigarettes causes a fire. It is not often possible to identify the cigarette packing[3] or substrates from the accident reports. To identify specific properties that may be involved as causative factors, one has to rely on laboratory simulations of cigarette-caused ignitions. Much more work has been done in the area of identifying soft furnishing characteristics which increase their cigarette ignition resistance (Section 6) than on identifying cigarette characteristics which reduce cigarette ignition propensity. One study of the relative propensity of selected commercial cigarette packings to ignite soft furnishings mockups has been completed under the Cigarette Safety Act [6]. A systematic investigation of the effects of certain cigarette parameters on their propensity to ignite soft furnishings is currently in progress.

The purpose of this literature survey is to provide a review of sources dealing with cigarette properties, substrate properties, and their interaction which may aid in the understanding of the mechanism by which cigarettes ignite substrates. It was written for readers having some familiarity with the field. Relevant patents are listed in Appendix B.

Thirteen data bases were searched as shown in Table 1. Also searched were sources not included in these data bases, e.g., special reports dealing with characteristics of cigarettes and soft furnishings and wildlife fires. Approximately 300 documents were initially identified; only about a third turned out to be germane to even a broad interpretation of the objective of this survey. Indeed, very little research has been published that directly relates cigarette combustion to substrate ignition mechanisms.

Table 1. Data Bases Searched

	From Year to Present
Chemical Abstracts	1967
Engineering Index Base Engineering Meetings	1979
Compendix (Engineering Information, Inc.)	1970
National Technical Information Service	1964
World Textiles	1970
Textile Technology Digest	1978
Paperchem	1967
CRIS/USDA	1983
BIOSIS Previews	1969
AGRICOLA	1970
FIREBASE	1900
Tobacco Abstracts	1975
World Patents	1963

[1]A soft furnishing substrate is a combination of cover fabric and padding material, with or without welt cord, in either the flat or the crevice (juncture of a horizontal and vertical furniture member) area. For example, the flat area of a piece of polyurethane foam covered with a cotton cover fabric; the crevice from the same material will be considered another substrate for the present purposes, as would be the same substrate but with the cigarette covered with a piece of sheeting, as is often used in testing the cigarette ignition propensity of soft furnishings (Appendix A).

[2]Ignition in this review will mean self-sustaining smoldering of the substrate; such smoldering may or may not lead to flaming. The term "self-extinguishing cigarette" has been widely used in many discussions of cigarettes with a low ignition propensity [e.g., 5]. However, even cigarettes which sometimes self-extinguish in air can ignite low cigarette ignition resistance substrates, as can some hand-rolled cigarettes which also commonly self-extinguish when not smoked [6-8]. Conversely, some cigarettes may burn their entire length without igniting high cigarette ignition resistance substrates. Consequently, we shall use, instead, the term "low ignition propensity" cigarettes in the following discussion. This term includes, but is not limited to, cigarettes which self-extinguish on a substantial number of substrates.

[3]A cigarette packing is usually defined as a commercial variety, described by its name, length, diameter, whether menthol or nonmenthol, whether with or without filter, and by its packing type.

One group of publications gathered for this survey was written by authors associated with the tobacco industry. It contains substantial information on such cigarette characteristics as burn rate and temperature of the burning cigarette. Among the variables discussed are tobacco type, cigarette dimensions and packing density, filter parameters and paper porosity, and additives. The major objective of these publications seems to be to obtain basic understanding of the burning cigarette, with emphasis on reduction of tar, nicotine, CO, and other smoke components. Some of these papers are discussed below for general information on the burn process of cigarettes. However, because of their purpose, they have two major limitations for the present objective: (a) most of the data were obtained during the puff, while furniture and wildlife material ignition by a cigarette would be during the "free burning" period, and (b) the results were obtained with the cigarette held in air, not in contact with a substrate where oxygen exclusion, heat sink effects, reradiation from the substrate, etc. can affect the progress of the cigarette burn and its energy transfer to the substrate.

Another large number of publications deals with the cigarette ignition resistance of soft furnishings. Test methods used to determine the cigarette ignition resistance of soft furnishings are listed in Appendix A. A discussion of papers on such test methods and the relative cigarette ignition resistance of various upholstery materials such as fabrics, padding, welt cords, decking, etc., is included in a recent review of all aspects of soft furnishings flammability [9] and is summarized in Section 6. However, most of this work was performed with one "standard" cigarette, with only the substrates varied. Relatively few reports describe experiments with more than one cigarette packing [6,7,8,10-17] (commercial cigarettes), [18,19] (research cigarettes).

About 100 patents have been issued which claim to reduce ignition propensity (Table 2 and Appendix B). Concepts in these patents include chemical modification of the tobacco column or paper by means of various additives, insulating material around the cigarette, obstacles to smolder progress in the tobacco column or on the paper, etc. Evaluation of these patents is beyond the scope of the present survey.

In the following, some basic cigarette characteristics will be discussed first, followed by the interaction between cigarettes and substrates. Then models of substrate smoldering and the relative cigarette ignition resistance of substrates will be discussed. This will be followed by a discussion of the relative ignition propensity of cigarettes.

Table 2. Summary of "Fire Safe" Cigarette Patents [115]

	No. of Patents		% of Patents	
Contain Ash and/or Reduce Heat Output	**30**		**32**	
• Paper treated with borates, silicates, chlorine containing latex, fire proof paint	16		17	
• Cigarette wrapped with aluminum foil, asbestos, fiber glass, etc.	13		14	
• Aluminum trihydrate added to tobacco	1		1	
Extinguish at Selected Point	**26**		**27**	
• Sliding or fixed non-combustible sleeve or band on cigarette	19		20	
• Insertions in cigarette (barrier disc of porous non-combustible materials such as asbestos, aluminum, etc.)	6			
• Air gap in tobacco in cigarette	1		1	
Extinguish at Butt End and/or Prevention of Hot Coal Falling Off	**21**		**22**	
• Non-combustible anchor or sleeve	3		3	
• Addition of extinguishing materials between tobacco and filter (capsules containing water, porous asbestos or metal discs, nylon band containing water)	18		19	
Additions to Cigarette Holders to Contain Ash and Prevent Contact with Burning Cigarette	**18**	**18**	**19**	**19**
TOTAL	95	95	100	100

Cigarette Characteristics

Factors Which May Affect Cigarette Ignition Propensity

As an aid in understanding the general trend of this review, some of the factors which the author thinks may affect the ignition propensity of cigarettes are listed below. Some of these factors are interrelated.

- Cigarette length. The tobacco column length affects the time a cigarette burns and thus the probability of it being dropped and causing ignition. (Since it takes some conscious effort to light a cigarette, one may assume that a short burn time reduces the probability that the smoker becomes inattentive and drops the cigarette stub. Even if he does, the time available for ignition of the substrate is likely to be shorter.)

- Burn rate. This is presented as a change in length or mass with time. Whether a cigarette is burning in air or is being puffed, the burn rate affects the remaining cigarette length and thus the probability of dropping the cigarette and of ignition. In addition, burn rate of cigarettes on a substrate, which may be lower than that in air, affects length of exposure of the substrate and the probability of ignition.

- Cigarette diameter. A decrease in cigarette diameter reduces the contact area between the cigarette and the substrate and reduces the available fuel.

- Packing density. Lower packing density (attained primarily by the use of expanded tobacco but also affected by the tobacco blend and cut width, i.e., the width of the tobacco strands) reduces the mass of available fuel.

- Tobacco type. The tobaccos used in various cigarette packings may vary in heat yield and burn rate due to variations in tobacco blend constituents and ratios, as well as in types and concentrations of flavorings and humectants.

- Paper parameters. Paper parameters cause differences in cigarette heat yield and burn rate. The paper permeability affects the flow of oxygen from the outside air to the combustion zone and the diffusion of pyrolysis gases from this zone to the outside. Chemicals are added to the cigarette paper as smolder accelerants or retardants and to modify the appearance of the ash [20].

- Filter characteristics. The presence and nature of filter tips also affects the flow of air through the cigarette [21]. Additional perforation is often provided in the paper covering the filter, reducing the flow of air through the tobacco column (ventilation; this is used to reduce the exposure of the smoker to smoke components). To compensate for the resulting change in combustion product yield or taste, other properties may be modified when a filter is added. Absence of a filter causes an increase in heat yield at the butt end [22].

The following factors, while not cigarette properties, are integral to any laboratory study of cigarette ignition of soft furnishings:

- Spatial time-heat flux profiles of the smolder front passing over a substrate. There are no references to this profile in the literature.

- Contact of cigarette and substrate. This is at least partially determined by the cigarette diameter, as noted above. Other factors are the substrate surface characteristics and any intumescent behavior of the cigarette paper, its ash, or the fabric, which could have an insulating effect.

- Substrate characteristics. Only some soft furnishings containing cellulose in either the fabric or the padding (cotton batting padding) or both, some acrylic fabrics, and some wildlife materials are susceptible to cigarette ignition. Both fabrics and wildlife materials must be of a certain minimum thickness and be fairly tightly packed.

- Ambient conditions. Ambient wind speed, relative humidity, and temperature, as well as moisture content of the substrate and perhaps of the cigarette may have an effect on ignition propensity.

General Characteristics of Cigarettes

Most commercial cigarette packings have been found to be quite similar in cigarette and tobacco column properties, except for considerable variation in length, paper properties and perhaps in tobacco type. The details are given below.

The largest study of the variability of some of the parameters of 128 commercial, U.S. cigarette packings was performed by Countryman of the U.S. Forest Service about 1980 [23]. His original premise was that certain cigarette packings are less effective initiators of wildlife fires than others. The length, diameter, weight, packing density, materials extractable with acetone such as crude fat, waxes, and gums, heating value (measured in a Parr adiabatic oxygen bomb) and ash content were determined. However, Countryman's work was terminated before these findings could be related to the ignition propensity of the cigarette packings.

Table 3 shows that most of the above cigarette and tobacco properties varied over less than a factor of two for the various cigarette packings, with much of that range due to the variation in cigarette length. The similarity of most cigarette packings was also mentioned in tobacco industry communications e.g., [5]. Acetone extractives are an exception; they exhibit both a wider range and a higher coefficient of variation. (The relevance of acetone extractives to burning characteristics is not obvious but they are listed here to illustrate the differences in tobacco column characteristics).

On the other hand, the cigarette paper varied considerably. The relatively large variation of paper weight as percentage of cigarette weight indicates differences in thickness or density (some of it is caused by tobacco column density variation). The variability of paper heating value and ash content per unit length indicates that the nature of the paper may also have varied. Furthermore, the heating value of the paper was found to be only about 70 percent of that of the tobacco, and its percent ash content considerably higher than that of the tobacco.

Countryman stated that the probability of wildlife matter ignition from a single cigarette is low, as compared to that from other sources such as matches and firebrands. Reasons given for this low ignition propensity are the low weight/volume ratio for cigarettes, the fact that they smolder rather than flame, and that the contact between cigarette and substrate is limited by the round configuration of the former as well as the natural roughness of the substrate. The author also states that the paper ashes first and may provide an insulating layer between coal and substrate.

Lotus [22] published similar results for 26 filter and 6 nonfilter cigarettes purchased in 1972. They are summarized in Table 4. He found somewhat different cigarette dimensions than Countryman found eight years later, but again found relatively small differences among the commercial cigarette packings he tested for the properties he measured.

Free Burn Characteristics of Cigarettes

Temperatures and burn rates of cigarettes in air have been widely reported. The absolute results for temperature depend on details of the measurement procedure, (location in coal, e.g., whether along the central axis or periphery; thermocouple size and orientation) but about 850°C seems to be the maximum reported for the period between puffs. It is not clear whether the lower temperatures reported in many studies are due to differences in the manner in which they were measured or are real results; the necessary details for clarifying this are frequently lacking. Consequently, reported temperature results obtained by various investigators can, at best, only be used for comparisons within each study, not between studies.

Burn rates between puffs reported in the literature ranged from 4 to 6 mm/min in still air. It should, however, be kept in mind that cigarette burn temperature and burn rate are greatly affected by presence of a substrate, as will be discussed in Section 3. Work conducted under the Cigarette Safety Act at the time of this writing attempts to clarify this phenomenon further.

Cigarette Burn Temperature

Laboratories connected with the tobacco industry have published some very sophisticated studies of cigarette temperatures. The majority of their results were obtained during the puff on smoking machines. For reasons given earlier, this survey will concentrate on the measurements obtained during free burning of the cigarettes, i.e., of cigarettes suspended in air between puffs. Some of the studies from laboratories outside the cigarette industry use less sophisticated methods but are reported here because they contribute concepts of possible interest [24-32].

A number of temperature measurement methods have been used: thermocouples inserted into the cigarette, optical pyrometry, infrared photometry, and X-ray scanning of beads embedded in the tobacco which melt at various temperatures. Most of these experiments were carried out with thermocouples. The effect of thermocouple size is discussed in a review article, as follows [24]. In one series of experiments, a decrease in thermocouple wire diameter from 0.100 to 0.025 mm increased the measured peak temperatures in cigarettes by 127°C. In another study, reduction of the thermocouple wire diameter from 0.20 to 0.05 mm increased the peak temperature readings from 656 to 812°C. No further increase in temperature was found with further decrease in thermocouple size. Based on the first study, it appears that accurate measurements of coal temperature require that thermocouples be no larger than 0.025mm.

Presented below are the *relative* effects of various parameters on peak temperatures reported by several authors. The absolute temperatures reported by these authors may differ because of the differences in measurement methods and thermocouple sizes. Temperatures were generally measured on the center line of the cigarettes.

Table 3. Characteristics of Commercial Cigarette Packings [22,25]

Cigarette Packings Acquired about 1980

Characteristics	Average	Standard Deviation	Coefficient of variation (%)	Range
Cigarette[a]				
Length of tobacco column (mm)	69.0	8.8	12.8	44.5-90.2
Diameter (mm)	7.9	0.3	3.3	6.6-8.5
Weight (g)	0.796	0.098	12.3	0.582-1.153
Heat (J/mm)[b]	188.7	14.7	8.0	143.3-230.7
Ash (g/mm)	0.0020	0.0002	10.0	0.0010-0.0024
Packing density (g/mm^3) x 10^3	0.2237	0.0129	5.8	0.1954-0.2742
Tobacco[a]				
Weight (% of cigarette weight)	94.2	1.0	1.0	91.6-97.7
Heating values[b] (J/g) x 10^4	1.6585	0.0456	2.8	1.5443-1.8677
(J/mm)	180.8	14.9	8.3	134.5-222.8
Ash (%)	16.3	1.3	8.1	11.8-19.4
(g/mm) x 10^3	1.78	0.19	10.9	0.97-2.21
Acetone extractives (%)	8.8	1.8	20.5	4.6-16.2
(J/mm) x 10^3	3.128	0.556	17.8	1.555-5.304
Paper[a]				
Weight (% of cigarette weight)	5.8	1.2	20.2	2.3-9.9
Heating value[b] (J/g) x 10^4	1.1737	0.0799	6.8	1.0288-1.4376
(J/mm)	7.8	1.7	22.0	3.0-12.2
Ash (%)	26.4	5.6	21.3	11.9-35.4
(g/mm) x 10^4	1.7	0.5	29.4	0.7-13.6
Peak Temperatures, °C				
Center of cigarettes[c]	780	–	–	763-802
Surface of cigarettes[d]	442	85	19	394-510
Time above 232°C, s[e]				
Center of cigarettes	100	15	15	67-122
Surface of cigarettes	80	17	21	62-94

[a] 128 cigarette packings
[b] Heating values measured in bomb calorimeter
[c] 35 cigarette packings
[d] 90 cigarette packings
[e] 8 cigarette packings

Table 3 contains Countryman's temperature data for some of the 128 cigarette packings, measured with 0.125 mm chromel/alumel thermocouples located at the center of the cigarettes or touching their periphery [25]. The cigarettes were held horizontally in air flowing at 1.3 m/s in the direction of the smolder front movement. The average temperature obtained with this size thermocouple at the surface was 470°C, and in the center 770°C. Countryman found that wood starts smoldering at or above 232°C. The time intervals over which the thermocouples indicated temperatures above this value averaged 100 seconds for the center and 80 seconds for the surface of the cigarettes.

In 1956, another investigator measured free burning temperatures of commercial cigarettes, and found an average center peak temperature of 730°C and an average periphery temperature of 565°C [26]. With the cigarette insulated with glasswool – to obtain maximum possible temperatures supposedly simulating the cigarette inside, e.g., a waste basket – the temperatures were 620 and 570°C, respectively.

Egerton, *et al.*, using the optical records of beads with differing melting points embedded in the tobacco, found a peak free burning temperature at the apex of the core of 820°C, while the maximum at the periphery was about 616°C [27].

Boyd, *et al.*, reported free burning and puff temperatures for a number of cigarettes in 1972 [29]. For (presumably British type) cigarettes, peak free burning temperatures were about 785°C, and puff temperatures, 820 to 850°C. The corresponding temperatures for hand rolled cigarettes were 620 and 780°C, and for cigars, 600 and 680°C. A certain pipe tobacco free burned in the pipe (with some puffing to keep it burning) at 640°C; the same tobacco free burned in a cigarette at 790°C. Boyd also found that puff temperatures of cigarettes from Australia, Great Britain, Denmark, France, Japan, and the U.S. were within the range of 800 to 900°C.

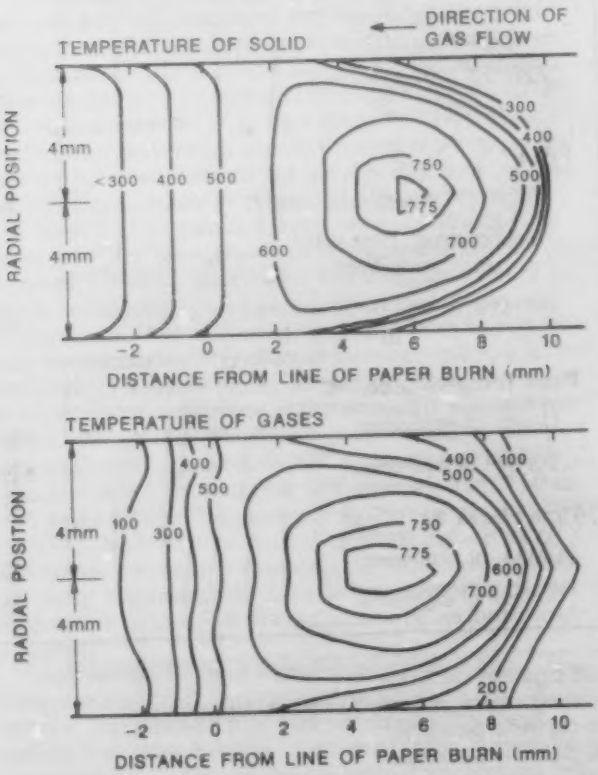
Gugan calculated that tobacco combustion would occur at about 1200°C with all the ash in place, and 820°C without the ash cover of the smolder cone [30]. His actual measurements produced lower values, about 820°C with the ash in place. He ascribed this to cooling by conduction through the ash, to the convective air flow pattern at the smolder cone, and to subsequent radiation and convection losses.

By use of infrared photometry, peak peripheral puff temperatures of typical cigarettes were found to be 830-900°C, and free burning temperatures about 700°C when the ash was partially removed from the smolder cone [31]. With the ash in place, the results were 830-900°C, and 500-600°C, respectively. Peak peripheral puff temperatures for cigarettes made with 100 percent Bright, Burley, and Turkish tobaccos varied only from 908-928°C.

Alteration of burn temperature was considered as a means to reduce the polynuclear aromatic hydrocarbons in the smoke [32]. However, a wide range of tobacco additives, in concentrations of up to 50 percent, including free radical inhibitors and initiators, organic and inorganic salts, a number of inorganic compounds including lead borate glass, certain catalysts and flame retardants, had only minor effects on puff peak centerline temperature.

In contrast to the previous papers which contained temperatures measured only in one or two locations, Baker published several profiles of temperature distributions in British cigarettes [28]. A free burn profile is reproduced in Figure 1; it gives temperatures separately for the gaseous and solid phases in the burn cone. The solid phase temperatures were measured by means of an infrared probe, the gaseous phase temperatures by means of thermocouples. He found relatively small differences between the solid and gaseous phase temperatures at any location. The maximum temperature measured – at the center of the cone, approximately 2 mm from its apex – was 775°C, at the periphery, somewhat greater than 500°C. The distances between the isothermic zones at the periphery are of interest. At the ciga-

Figure 1. Temperature distribution in a cigarette during free burning (°C).



rette surface, the 500°C gas and solid temperature zones extended from approximately the paper burn line to 2 mm into the smolder cone. The corresponding distances for the 300°C or higher solid phase zone were 3 mm from the paper burn line towards the butt end to 5 mm into the smolder cone for the solid phase. For the gaseous phase, the corresponding distances were 1 and 8 mm. As will be discussed later, burn cone geometry and very probably temperature distribution change when the cigarette is in contact with a substrate.

Cigarette Burn Rate

Burn rate is of interest to the cigarette industry because it affects the number of puffs per cigarette, levels of smoke constituents, and other properties. A fast burn rate was also often hypothesized to correlate with increased ignition propensity. However, results of experimental work conflict with this concept [6,19]. Ignition of a substrate requires not only a critical heat flux but also a critical exposure time. As will be discussed in Section 4, below, the cigarette burn rate is altered by the presence of a substrate. Free burn rate is briefly discussed here because it can be considered a basic characteristic of cigarettes.

This discussion is based primarily on several major studies [33-37]. American and Hungarian type cigarettes are discussed. In three of these studies, the burn rate was measured on horizontally suspended cigarettes. Rice's study was conducted on Canadian cigarettes containing essentially all bright tobaccos; vertical cigarettes were tested with the burn moving downwards [37]. The effects of various parameter changes were generally found to be similar in all studies.

The basic device for measuring cigarette burn rate consists of a holder for the butt end of the cigarette, trip threads touching the horizontal cigarette (usually 40 mm apart), and a timer to determine the interval at which the threads break [33]. Burn rate measured without puffing is called the "free" or "static" burn rate. Linear burn rate is usually expressed in mm/min and mass burn rate in mg/min. The latter is usually calculated from the linear burn length and the packing density.

Corbet and Schurer described an apparatus for measuring the burn rate of cigarette paper separately, with bottom ignition of vertically held specimens [38]. Burn velocities of 155 to 215 mm/min were observed; these velocities are greatly in excess of those of cigarettes. Some of the papers did not burn.

The burn rate of 14 filter and three nonfilter U.S. cigarettes, sampled in 1980, varied from 4.1 to 5.9 mm/min [39]. By contrast, rates of 1.8 to 3.6 mm/min were reported in 1930 [16,17]. With the coal ends down, the burn rate of a 1980 cigarette packing increased by 30 percent, with the coal end up, it decreased by 6 percent [39]. An increase in external air movement in the direction of the burn from 3.2 to 9.0 km/hr increased the linear burn rate from 5.0 to 8.0 mm/min. A further increase in wind speed decreased it slightly to 7.5 mm/min. Wind perpendicular to or against the burn direction extinguished some of the cigarettes.

Japanese investigators found no significant differences in horizontal and vertical (coal end down) burn rates for cigarettes from three packings [14]. The method by which these somewhat unexpected results was obtained was not described in detail. The burn rates of these cigarettes were not affected by the packing densities indicating that other, nondisclosed factors affected the burn rate. The ignition propensities of these cigarettes on a number of upholstery substrates did not vary significantly.

Ninety-five cigarette packings available in Germany in 1982 had burn rates from 2.1 to 5.1 mm/min [40]. This is a lower range than that given for U.S. cigarettes. This may be a true finding or may be due to a difference in the measuring method, which is not described in the German paper. A specially low burn rate was found for some oval cigarettes.

Rice found the mass burn rate to be directly proportional to the cigarette circumference for any one tobacco blend/paper combination [37]. Resnik, *et al.*, reported that an increase in circumference from 23 to 26 mm decreased the linear burn rate from about 5.5 to 4.7 mm/min and increased the mass burn rate from 62 to 77 mg/min [33,34]. Arany-Fuzessery, working with Hungarian cigarettes, found similar effects of the diameter on the two burn rates [36].

Resnik, *et al.*, found that the mass burn rate was generally not affected by packing density [33,34]. The linear burn rate was approximately inversely proportional to packing density, with an increase in packing density from 0.22 to 0.36 g/cm^3 producing a decrease in linear burn rate from 6.7 to 4.2 mm/min.

Resnik, *et al.*, also found that cigarettes made from three tobacco types to the same firmness (which may have resulted in different tobacco column weights) differed in burn rate, as follows [33]:

	Burn rate	
Tobacco	mm/min	mg/min
Turkish	3.3	52
Bright	5.3	69
Burley	6.2	77

Increasing the cut width from 0.4 to 1 mm resulted in a decrease of burn rate from 6.0 to 5.2 mm/min [35]. For a Hungarian tobacco blend, an increase in cut width from 0.57 to 1.19 mm decreased the linear burn rate by approximately 8 percent and the mass burn rate by 17 percent [36]. Rice, *et al.*, found that an increase in cut width from 0.35 to 0.61 mm decreased the mass burn rate from 66 to 54 mg/min [37].

The paper characteristics can be adjusted to modify the cigarette burn rate somewhat. The major variables used for this purpose are: fiber composition, weight and bulk density,

the type of filler and its concentration and distribution throughout the paper, air permeability[4] or porosity, and smolder promoting chemical additives [20,41,42]. Permeability is generally expressed as "CORESTA," in $cm^3/min \cdot cm^2 \cdot cbar$; it increases with increasing air permeability. Alternatively, air permeability is often expressed in older literature as a "Greiner" number, i.e., the number of seconds required for 50,000 mm^3 of air to pass through 1,950 mm^2 of paper.[5] Consequently, the higher the Greiner number, the lower the porosity.

Permeability can be increased by electrostatic, laser, or mechanical perforation of the paper. Other means are used to vary the "inherent porosity" such as manipulation of the fibers during paper forming, reduction of paper weight, and/or use of paper fillers, e.g., $CaCO_3$ [20]. These methods have different effects on burn rate: increasing the porosity mechanically does not affect the mass burn rate, while increasing the inherent paper porosity increases both the linear and mass burning rates [33-37,42]. However, beyond a permeability of about 80 $cm^3/min \cdot cm^2 \cdot cbar$, no additional increase was found [36]. These relationships held for widely varying cigarettes.

An empirical formula for computing the effects of the cigarette property changes on the mass burn rate was proposed by Rice, *et al.* [37]:

$$B = \frac{C}{Cw}[Bw + 0.70\,(Mw - M) + 0.34\,(Pw - P) - 0.17\,(Tw - T)] \quad (1)$$

where B = "predicted" rate of burn, mg/min
Bw = rate of burn of "measured" cigarette, mg/min
C = circumference of "predicted" cigarette
Cw = circumference of "measured" cigarette
M = moisture content of "predicted" cigarette
Mw = moisture content of "measured" cigarette
P = paper porosity of "predicted" cigarette
Pw = paper porosity of "measured" cigarette
T = cuts per inch of tobacco of "predicted" cigarette
Tw = cuts per inch of tobacco of "measured" cigarette

By correcting for packing density, equation 1 can be readily modified to make possible the prediction of linear rate of burn:

$$B_L = \frac{LC}{WCw}[Bw + 0.70\,(Mw - M) + 0.34\,(Pw + P) - 0.17\,(Tw - T)] \quad (2)$$

where L = length of "predicted" cigarette (tobacco portion only)
W = weight of "predicted" cigarette (tobacco portion only)
B_L = linear rate of burn, mm/min

These formulas were confirmed by actual burn rate measurements on experimental cigarettes with two levels of each of the following variables: cigarette weight, circumference, cut width, moisture content, and paper porosity [37].

Other parameters also have been reported to have an effect on the burn rate, including relative humidity and smolder promoters or retardants. Three studies showed that burn rate decreases with increasing cigarette moisture content, while cigarette temperatures are not found to be greatly affected [15,35,43]. When conditioned at 20°C and 67 percent relative humidity, a commercial cigarette burned at 4.8 mm/min; at 28°C and 25 percent relative humidity, at 5.6 mm/min [39]. Another author reports a burn rate decrease of 12 percent with an increase in moisture content from 12 to 16 percent, and the temperature constant [33]. Rice, *et al.*, showed that an increase in moisture content of cigarettes from 4 to 20 percent caused a decrease in vertical mass burn rate of 10 mg/min for three cigarettes varying in tobacco type and thus burn rate [37]. However, increasing concentrations of two humectants added to the tobacco, from 0.2 percent glycerol and 0.2 percent propylene glycol to a 1.4 percent concentration of both humectants produced the following small effects: increase in moisture content from 11.3 to 11.9 percent, free burn rate increase from to 4.9 to 5.3 mm/min, and mass burn rate increase from 61 to 66 mg/min [33].

Tobacco additives have been studied widely. Below we present summaries of some of these studies. In one of these, the same concentration of cations was added to all experimental cigarettes [41]. The effects on free mass burn rates were as follows, in descending order:

For Na-salts: bicarbonate = carbonate > nitrate > phosphate, dibasic phosphate, chloride > sulfate > monobasic phosphate;

For nitrate and acetate, the order was $Na \geq K > Li > Ca > Mg > NH_4$. Ca, Mg, and NH_4 nitrates could not sustain the smolder of a model cigarette by themselves.

By the further addition of K-maleate (K, 0.5 percent) or Na-malate (Na, 1.0 percent) as a coexistent salt, the order of the burn rate retarding effect of NH_4-salts was sulfate > chloride > nitrate ≥ carbonate = acetate.

Chemical additives to the paper can be mixed with the cellulose slurry as fillers or applied as coatings to the paper surface in the form of very fine crystals [20]. Such chemicals can be used to affect burn rate or to affect the nature of the ash, e.g., white or mottled appearance. Some that were tested in the laboratory are listed below [20].

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[4]"Permeability" shall be used as a term for air passage due to both "inherent porosity" which can be regulated in paper manufacture, and postpaper forming (mechanical or electrostatic) perforation.

[5]CORESTA 10 corresponds roughly to a Greiner 45 reading; 30 to 18; 50 to 12.5; and 70 to 10.

Burn Accelerators	Ash Conditioners	Burn Retardants
Alkali metal citrates	$NH_4H_2PO_4$	$NaBO_3$
Alkali metal tartrates	Urea	$Na_2B_4O_7$
Alkali metal acetates		Na_2MoO_7
Alkali metal malates		$AlCl_3$
Alkali metal formates		
Alkali metal phosphates		
Alkali metal nitrates		
Alkali metal sulfates		
Alkali metal carbonates		
Alkali metal halides		

Citrates and phosphates are the most widely used additives to today's cigarette papers. On paper which had burn rates of 4.0 mm/min and 53 mg/min when untreated, a 2 percent concentration of sodium citrate raised the burn rates of cigarettes to 5.5 mm/min. and 72 mg/min, while other citrates had less effect. Similar burn rate increases were observed when certain phosphates (1 percent PO_4^{-3}) and sodium salts (0.5 percent Na^+) were added to the paper [34].

In summary, the effects of changing the inherent and mechanically or electrostatically-induced paper permeability and of modifying chemicals on the free burn process have

Table 4. Characteristics of Commercial Cigarette Packings [23]

Cigarette Packings Acquired about 1971

Characteristics	Average	Standard Deviation	Coefficient of variation (%)	Range
A. 26 filter cigarette packings				
Cigarette				
length (mm)	86	6.0	7.0	80-100
weight (g)	1.05	0.07	6.7	0.96-1.23
butt temperature (°C)	659	25	3.8	601-711
Tobacco				
weight (% of cigarette weight)	74.4	5.7	7.6	59.7-80.3
heat (J/mm^3)[a]	4.2	0.1	2.4	3.9-4.6
packing density (g/mm^3) x 10^{-3}	0.27	0.01	3.8	0.254-0.294
B. 6 Non-filter cigarette packings				
Cigarette				
length (mm)	79	7.0	9.0	70-80
weight (g)	1.03	0.05	5.8	0.957-1.094
butt temperature (°C)	695	39.0	5.6	627-722
Tobacco				
weight (% of cigarette weight)	94.76	0.33	0.4	94.24-95.20
packing density (g/mm^3) x 10^{-3}	0.27	0.01	3.7	0.259-0.286
heat (J/mm^3)[a]	4.3	0.20	4.7	4.1-4.5
Paper				
weight (% of cigarette weight)	5.23	0.33	6.4	4.80-9.76

[a]Heating values measured in bomb calorimeter.

been extensively studied empirically, but are not well understood [20,42]. The effect of some of these factors on ignition propensity has been investigated as part of the work under the Cigarette Safety Act and will be reported in the near future.

The following is a qualitative summary of the effect of cigarette construction variables on burn rate:

	Effect on Burn Rate	
Increase in	Linear, mm/min	Mass, mg/min
Cigarette		
circumference	decrease	increase
moisture content	decrease	decrease
Tobacco[a]		
packing density	decrease	no effect or decrease
cut width	decrease	decrease
Paper		
permeability		
inherent	increase[b]	increase[b]
mechanical	no effect	no effect
citrate content	increase	increase

[a]Tobacco type and additive (humectants, etc.) content also affect burn rate.
[b]No effect beyond 80 CORESTA.

Temperature and Burn Rate of Cigarettes Burning on Substrates

Non-Combusting Substrates

The temperatures at the center lines of 26 filter and 6 nonfilter cigarettes placed on asbestos board were measured in 1972 by Loftus [22] using 0.05 mm chromel/alumel thermocouples. The average results, along with some physical property data, are shown in Table 4. Loftus reported that there were no differences between peak, center line temperatures in the filter and non-filter cigarettes when measured at 25 and 51 mm from the butt end. At 3.2 mm from the butt end, the nonfilter cigarette temperatures were on the average 36°C higher than the filter cigarette temperatures.

A similar study had been carried out in 1969 by Behnke. He used a highly conductive, 0.075 mm thick, copper sheet (size not given) as the substrate, with 0.25 mm chromel/alumel thermocouples attached to the copper plate [43]. Obviously, a copper sheet differs considerably in heat conductivity and other characteristics from fabrics used in upholstery, but Behnke's work may still be valid for comparison of the properties of various cigarette packings. The filter and nonfilter cigarettes were preconditioned by drying at 110°C for 16 hours followed by desiccating at room temperature for 8 hours. Some were tested dry, immediately after removal from the desiccator, and others after a further conditioning at 24°C and 65 percent relative humidity. The cigarette temperatures and heat flux (as measured by the temperature rise of the copper plate) results for 16 cigarette packings are summarized in Table 5. The temperatures were much lower than those measured by Loftus with the cigarettes resting on the asbestos sheet with the thermocouples in contact with the cigarette. For comparison, Behnke reported conditions at which a cotton fabric (undefined) was found to ignite under several experimental conditions: in a heated vessel at 385°C; on a hot plate at 465°C; and in contact with a hot wire at 518°C. A radiant exposure of 28 kW/m² for 30 seconds (equivalent to a black body temperature of about 560°C) also ignited the fabric.

We conclude the following from Behnke's work:

- There were no consistent effects on burn temperature or heat flux due to drying the cigarettes. This has also been reported by others for temperatures inside cigarettes [15,35].
- There were no systematic differences between the filter and nonfilter cigarettes; since these were commercial packings, parameters other than the presence or absence of a filter undoubtedly were also varied.
- The temperatures and the heat flux levels measured on the copper sheet are sufficient to account for ignitions of cellulosic soft furnishings and wildlife [25], even though the reported values are probably lower than actual peak values.

Smolder-Prone Substrates

Below is a review of temperatures measured inside cigarettes, at their interface with substrates, and inside polyurethane substrates. The core temperatures of cigarettes

Table 5. Cigarette Temperature and Heat Flux Results with the Cigarette Resting on a Copper Plate [43]

16 Commercial Cigarette Packings Acquired in 1969

Conditions	Average	Standard Deviation	Coefficient of variation (%)
A. Temperatures, °C			
dry[a]	490	35	7.1
conditioned[b]	492	45	9.1
B. Heat flux, kW/m²			
dry	40.6	6.7	16.4
conditioned	40.6	6.4	15.7

[a]dried at 110°C, cooled in desiccator 8 hours.
[b]dried and cooled as above, conditioned for 8 hours at 24°C and 65% r.h.

were found to be lower when they burned on smolder-prone substrates than when they were burned in air. Substrate ignitions were shown to occur at cigarette centerline temperatures as much as 250°C below those of the cigarette burning in air. The cigarette centerline temperature rose only after the substrate started smoldering and there was heat feedback. One could question whether the time-temperature characteristics of cigarettes obtained in air are relevant to their ignition propensity. A more detailed summary of these findings is given in Section 3.4.

Several investigators [44-51] placed cigarettes on substrates consisting of cellulosic (cotton or rayon) fabrics over glass fiberboard, polyurethane foam, and other paddings. Both flat and crevice substrates were used. Temperature measurements were carried out with thermocouples embedded inside the cigarette, at the cigarette/substrate interface, on the fabric surface under and at various distances from the cigarette, and inside the padding at various distances from the cigarette. As will be seen, both the peak temperatures and the duration of the time-temperature peaks determine whether selfsustaining, smoldering ignition of the substrate occurs or whether the substrate self-extinguishes. Unfortunately, some of the papers which present time-temperature curves did not differentiate between occurrence of self-sustaining ignition, or smoldering of the substrate in the vicinity of the cigarette and self-extinguishment of the substrate when the cigarette went out.

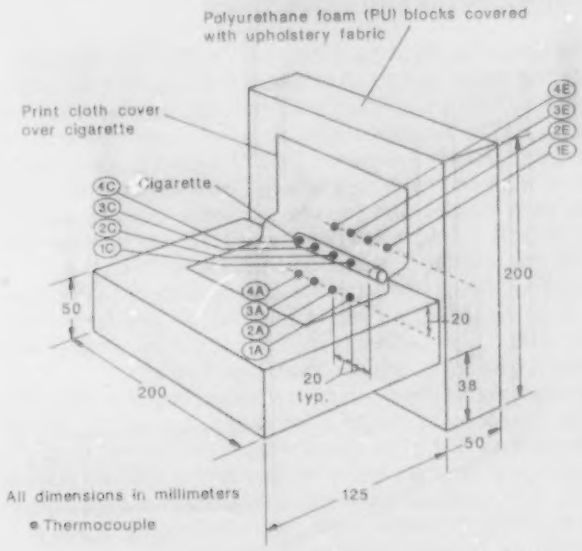
Furthermore, the degree of contact between the thermocouple and the substrate or the cigarette is a somewhat uncontrolled variable in such experiments. Cellulosic materials shrink and often visibly move during charring; cavities bordered by molten material or char are formed in polyurethane foam. These can affect the contact with the thermocouple and the resulting temperature readings.

Investigators at the Massachusetts Institute of Technology

The most extensive work in this area was carried out by Salig, *et al.* [44]. This was summarized and extended by Tesoro [45]. The following discussion will start with temperatures measured inside the cigarettes, followed by those obtained at the fabric/padding interface and inside the polyurethane foam. Both flat and crevice geometries and covered and uncovered cigarettes were used, as well as a set of three fabrics, with one of them finished in various ways.

Figure 2 shows Salig's experimental arrangement for the cigarettes on the substrates. Figure 3 shows the time-temperature traces obtained by thermocouples located about 25 mm from the tips of the cigarettes, at the cigarette centerline. The highest, and by far the narrowest, peak at 700°C was obtained with the cigarette burning in air. The relatively low peak temperature reported may have been due to use of large diameter thermocouples which were not described in these papers. When the cigarette was placed on a substrate consisting of a 120 g/m^2 cotton printcloth over polyurethane foam[6] in a crevice configuration, with the cigarette covered with another piece of the same printcloth, the substrate did not ignite. However, the cotton fabric showed some localized char and the polyurethane foam showed a 10mm deep trough. The peak temperature inside the cigarette was about 620°C, i.e., somewhat lower than that inside the same cigarette burning in air. The temperature peak was wider, indicating a lower burn rate. Explanations offered by the authors are the heat sink effect of the substrate and competition for the available oxygen by the substrate (which would be minimal if the substrate did not ignite); slowing of the oxygen supply rate by the fabric on top is an additional factor.

Figure 2. Test arrangement for crevice tests.



When the cigarette was placed on a polyurethane foam block covered with a scoured and bleached, 320 g/m^2, cotton duck, ignition occurred. The temperature rose to a 500°C "plateau" (slightly descending in this case, essentially level in others) and then ascended to a peak of about 620°C. During the plateau time, smoke generation increased and the smoke assumed a yellow color, indicating polyurethane foam pyrolysis and probable smolder. Thus, polyurethane ignition occurred at a cigarette core temperature of about 500°C. After ignition, heat feedback from the smoldering polyurethane foam increased the cigarette core temperature.

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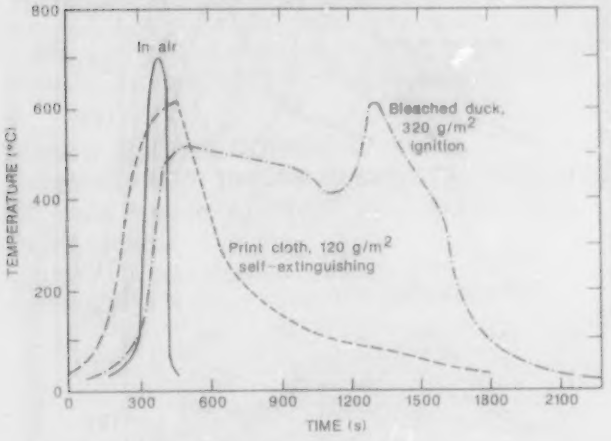
[6]*Polyurethane was Grade 2715-27-ILD polyether/polyurethane foam from Olympic Products Company, Greensboro, NC, density 24 kg/m^3, no flame retardant, 4.8 percent nitrogen, 61.3 percent carbon, 9.0 percent hydrogen, and 24.7 percent oxygen.*

Figure 3. Time/temperature relationships inside cigarette core in air and on two substrates.

—— Cigarette burning in air.

– – – Cigarette in crevice of printcloth upholstery fabric/PU block mockup; cigarette covered by small piece of fabric (printcloth/ PU/crevice/covered).

– · – Cigarette in bleached duck/PU/crevice/covered mockup.



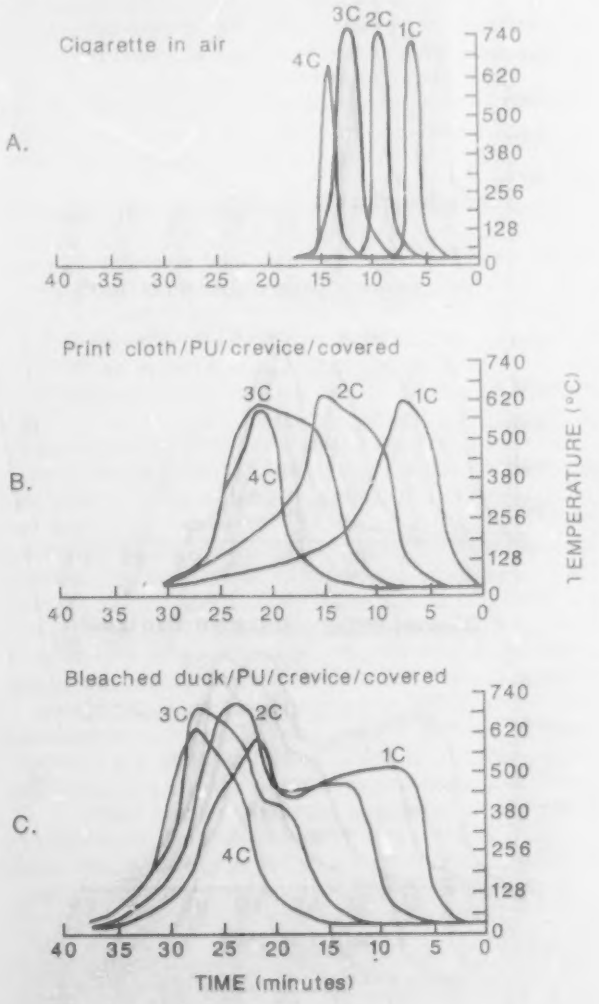
The sequence of events was as follows: the cigarette causes smoldering of the fabric, and only if the fabric is sufficiently smolder-prone can it ignite the polyurethane foam. Essentially none of the polyurethane foam types presently used in furniture, including the polyurethane foam used in this work, ignites from a cigarette alone unless they are covered by a smolder-prone fabric [9].

Figure 4 shows time/temperature traces for four thermocouples embedded in the cigarette core; the first traces ("1C") are the ones shown in Figure 3. In the majority of the cases, the mid-column (second and third) peaks inside the cigarettes were slightly higher than the first ones and the last peak was lower than the others, perhaps due to higher heat losses near the cigarette butt.

The shapes of the sequential peaks inside the cigarette burning on the bleached duck substrate differed considerably, indicating a complex interaction between the fabric, polyurethane foam, and the cigarette during ignition of first the fabric and then the polyurethane foam. The above-mentioned plateau decreased in height and width with smolder progress through the cigarette. This indicates that as the substrate smolder grew, the cigarette temperature was at first lowered. When the polyurethane foam started smoldering about 20 minutes after cigarette placement, substantial heat feedback to the cigarette core apparently occurred.

The cigarette glowing zone in air was reported to have been approximately cylindrically shaped, with a 10 mm dimension along the cigarette axis. Covered cigarettes on a printcloth substrate had a conical burn zone, with a 15 mm length when the cigarette had burned about half its length.

Figure 4. Time/temperature relationships measured in four locations inside cigarette core.
Conditions as in Figure 3.



and 25 mm near the butt. With heavier, more smolder-prone fabrics, cigarette smolder zone lengths of up to 33 mm were observed. Without a cover over the cigarette, the smolder region in contact with the substrate often precedes that in the center of the cigarette.

Additional Printcloth Experiments: Salig [44] performed a number of other experiments with the printcloth/polyurethane foam substrate with thermocouples at various locations on and in the substrate. The embedded thermocouples were placed 20 mm below the surface of the polyurethane foam. In general, ignition did not occur in these experiments; however, Salig reported one ignition of the polyurethane foam even though the fabric showed little evidence of smoldering. This appears to be a rare occurrence, and is mentioned here for the record.

Figure 5A shows the traces obtained by thermocouples located at the fabric surface where it contacts the cigarette lying in the crevice. There was only localized charring in the fabric and a small cavity in the polyurethane foam, indicating that no ignition occurred. The temperatures measured in this manner were about 200°C lower than those measured on the cigarette centerline, and the peaks were about the same width.

Figure 5A also shows that temperatures with cigarettes covered with the printcloth were somewhat lower, and the peaks wider, than those for uncovered cigarettes. (Covered substrates have a lower cigarette ignition resistance than uncovered substrates, as will be discussed later.) The peak temperature measured 20 mm below the cigarette in the horizontal polyurethane foam was reported to be 100°C higher for the covered than the uncovered cigarette (not indicated in the figure).

(Somewhat different effects of covering cigarettes were obtained in another study in which chromel/alumel thermocouples (no size given) were placed at the surface of glass fiberboard along, and 25 mm above, and below the crevice line [46]. The peak temperatures shown by the eight thermocouples for uncovered cigarettes, resting directly on the glass fiber board, ranged from 200 to 300°C, and the average time above 200°C registered by the eight thermocouples was approximately 20 seconds. With one piece of sheeting covering the cigarette, peak temperatures ranged from 240 to 350°C and average time above 200°C was again 20 seconds. For two cover sheets, the corresponding results were 270 to 350°C and 30 seconds. It is possible that more oxygen was available to cigarettes on glass fiberboard than to those on a fabric/polyurethane foam substrate, and that this, along with the heat containment by the cover, accounts for the higher temperatures with cover.)

Salig's Figures 5B and 5C show temperatures obtained with printcloth/polyurethane foam/crevice/covered cigarette substrates, 20 mm inside the horizontal and vertical polyurethane foam. No ignition occurred. The traces for these two locations are similar, with peak temperatures of about 300°C. This is about 150°C less than in the fabric, and 300°C less than inside the cigarette.

Figure 5. Time/temperature relationships at fabric surface and 20 mm inside vertical and horizontal PU—Printcloth.

Printcloth/PU/Crevice. No ignition.

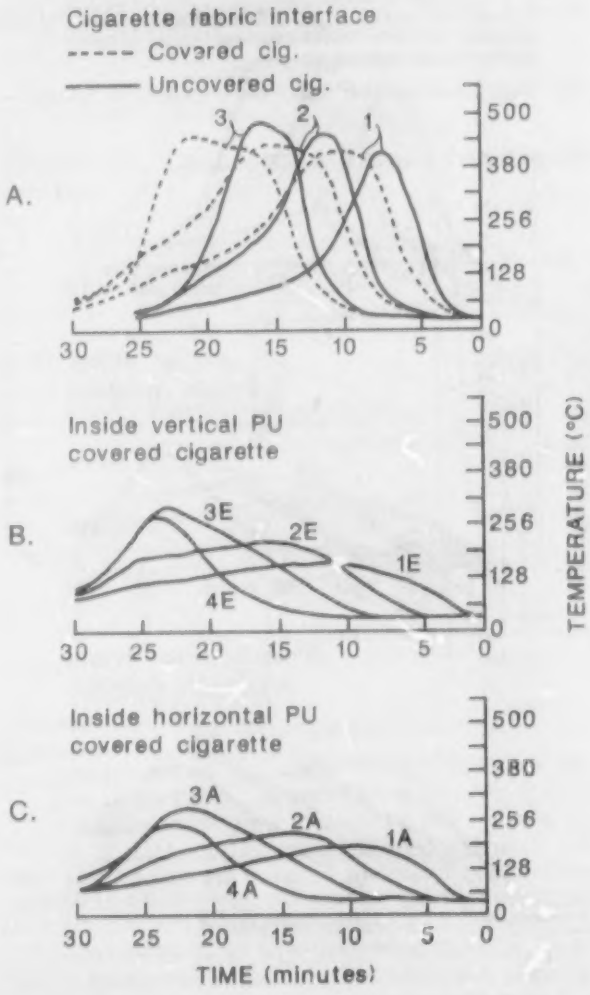


Figure 6 presents similar traces, but with two cigarettes placed end-to-tip into the printcloth/polyurethane foam crevice. In this configuration, ignition occurred at about the time when half of the second cigarette was consumed, indicating the importance of time of exposure. At about 40 minutes after ignition, peaks of approximately 700°C

occurred inside the cigarette and of 450°C 20 mm inside the polyurethane foam. The second thermocouple inside the horizontal polyurethane foam reached a temperature peak at the end of the experiment, indicating, most likely, that the smolder wave moved back through incompletely pyrolyzed material. Thermocouples 5-7 exhibited the plateau which occurs during substrate ignition.

Other Fabrics: Figures 7 and 8 show temperatures inside the cigarette core and the horizontal and vertical polyurethane foam for igniting substrates, both containing the relatively heavy duck fabric. Figure 7 shows results for the fabric in its "greige" (raw cotton, unscoured) state, Figure 8 after scouring and bleaching. The greige fabric is expected to contain alkali metal ions, primarily Na^+ and K^+, which are known to be smolder promoters [48,52,53]. For the greige fabric, the temperature inside the cigarette reached 650°C,

Figure 6. Time/temperature relationships inside cigarette core and 20 mm inside vertical and horizontal—Printcloth.

Ignition with two cigarettes, end-to-tip. Printcloth/PU/Crevice/ Covered. Ignition.

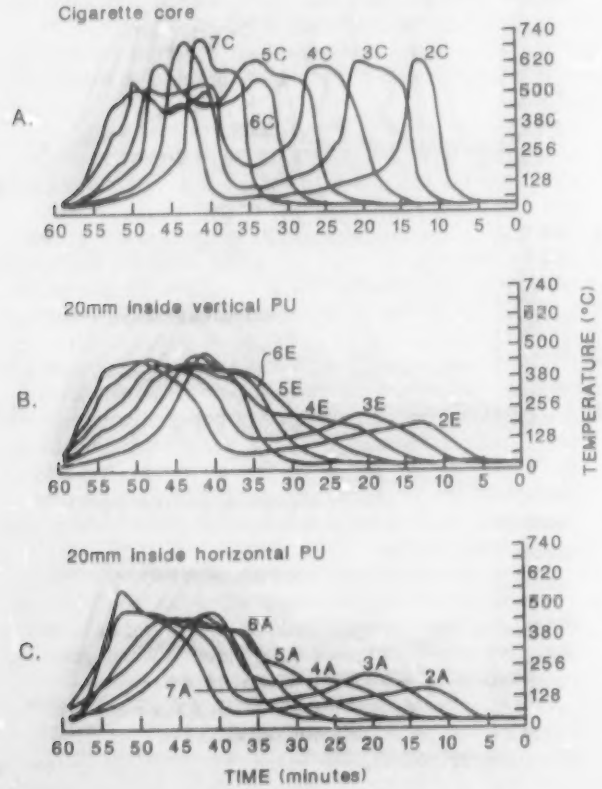
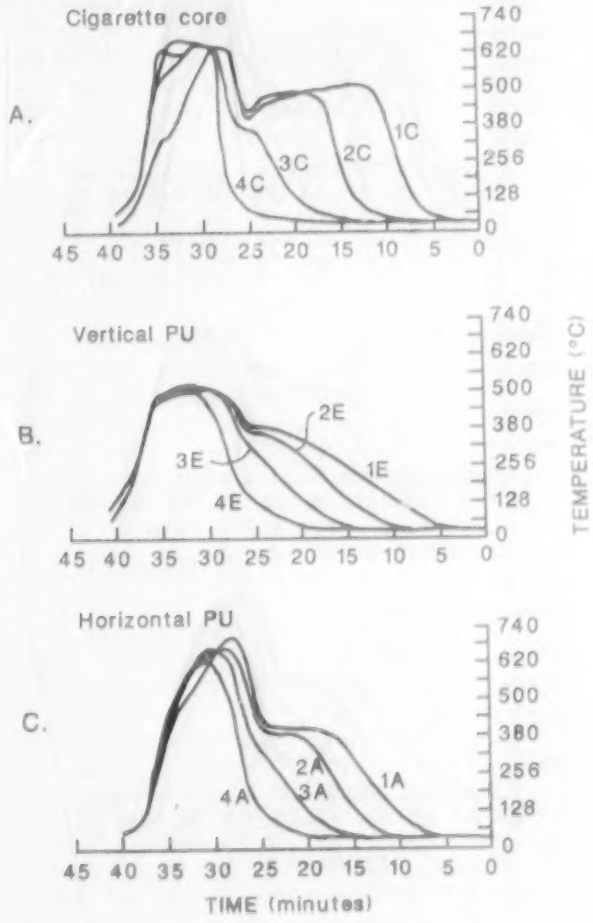


Figure 7. Time/temperature relationships inside cigarette core and 20 mm inside horizontal and vertical PU--Greige Duck Fabric.

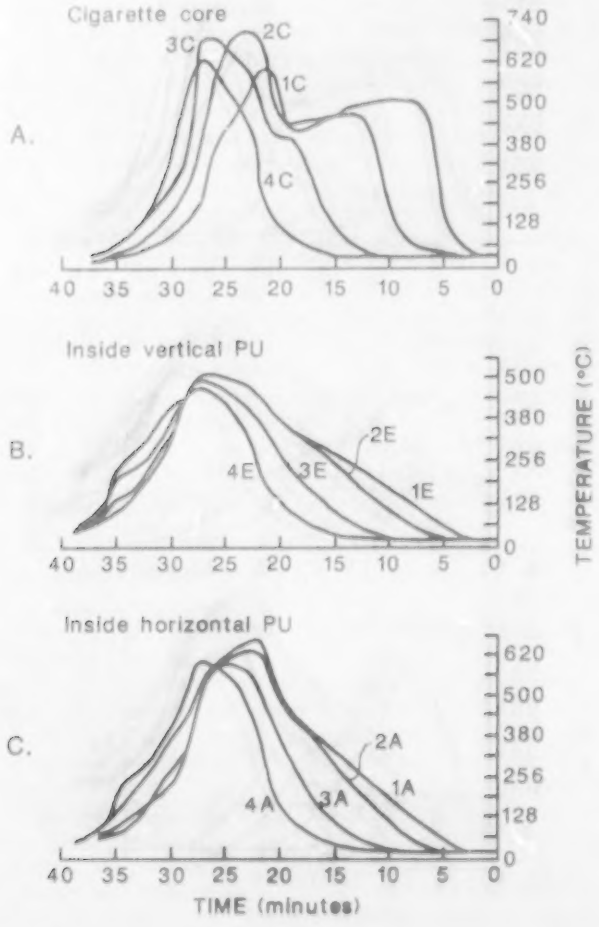
Greige Duck/PU/Crevice/Covered. Ignition.



20 mm inside the vertical polyurethane foam, 500°C, and inside the horizontal polyurethane foam, 700°C. The temperatures observed for the industrially scoured and bleached fabric were similar but the peaks were somewhat narrower except inside the horizontal polyurethane foam. With many of the alkali metal ions supposedly removed by home laundering, the substrate did not ignite, and temperatures inside the polyurethane foam stayed below 450°C (no figure).

Figure 8. Time/temperature relationships inside cigarette core and 20 mm inside vertical and horizontal PU -- Bleached Duck Fabric.

Bleached Duck/PU/Crevice/Covered. Ignition.



It is noteworthy that the temperatures inside the horizontal polyurethane foam were considerably higher than those reached inside the vertical polyurethane foam. Similar observations were made by other investigators [46], who warned that reliance on upward char length measured on the fabric surface as the pass/fail criterion, as practiced by UFAC [54], may be misleading. In fact, not only extensive smoldering but eventual flaming was reported for horizontal substrates which could perhaps be rated "passing" on the basis of the upward char length criterion.

Figure 9 shows traces obtained from thermocouples spaced every 20 mm along lines 20 mm inside the vertical and horizontal polyurethane foam covered with the bleached duck. It seems noteworthy that all peaks inside the horizontal polyurethane foam occurred at almost the same time, regardless of the distance from the crevice. The peak height decreased with increasing distance from the crevice line. In the vertical polyurethane foam, time to peak increased with increasing distance from the crevice line. Again, the temperatures were higher inside the horizontal than inside the vertical polyurethane foam.

Other Investigators

In a recent study by Ihrig, *et al*., four experimental cigarettes were allowed to burn on a variety of substrates [19]. The cigarette variables were circumference (21.8 and 24.8 mm) and packing density (0.15, 0.20, and 0.28 g/cm^3); the lower values are claimed to be the lower practical limits which can be produced. Other variables which may affect cigarette ignition propensity (e.g., paper porosity and smolder accelerant or decelerant content [5]) were not included in this study. The substrates consisted of 33 cellulosic fabrics, ranging from 135 to 775 g/m^2, which covered the range available in local retail stores in 1984. Each fabric was used over a polyurethane foam and over cotton batting padding, in three configurations; flat, rectangular crevice, and acute angle crevice. The fabric ignition temperature, air permeability, moisture content, density, and sodium and potassium ion contents were determined, as were burn rate and heat output characteristics of the four cigarettes. In addition, a method was developed to measure the smoldering proclivity of the individual yarns sampled from the fabrics.

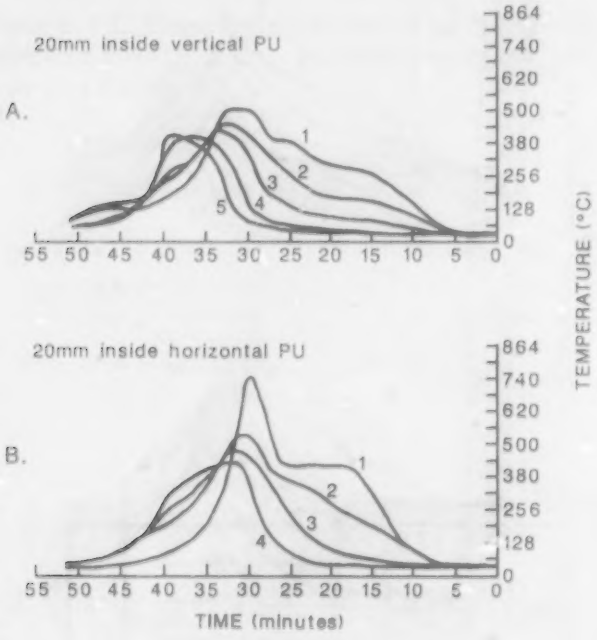
We draw the following conclusions from this work:

- Differences in the propensity of the cigarettes to ignite was shown on 29 of the 181 substrates. (Some tests were not performed due to shortage of fabric.)
- The results indicate that a combination of low diameter and low packing density may further decrease the ignition propensity of cigarettes. This is in agreement with earlier findings on commercial cigarettes (which, however, may also have varied in other parameters) [6,7,8,10-13].
- The ignition propensity of the cigarettes was correlated to the heat output from the cigarettes, in calories/cigarette.
- The cigarette ignition resistance of polyurethane foam and cotton batting mockups decreased with increasing alkali metal ion concentration in the fabrics. Among the polyurethane foam mockups, increasing fabric weight and decreasing fabric density also were found to reduce cigarette ignition resistance. Most cotton batting crevice mockups ignited; among the flat cotton batting mockups, cigarette ignition resistance seemed to decrease with decreasing fabric weight, perhaps due to the generally high alkali metal content of cotton batting which may come into play earlier if the fabric is light.
- Over the range studied, cigarette variables were less important than fabric or padding variables in predicting probability of ignition.

- The smoldering proclivity of the yarns increased with increasing alkali metal content of the fabrics. This test, causing the yarn to smolder and observing the distance and duration of smolder, could perhaps be adopted by UFAC or the fabric industry as a simple, predictive method for the efficacy of final rinsing of fabrics. If yarns which have been immersed in soft water and dried smolder less than the yarns tested as taken from the fabric, the final rinse probably has not removed the alkali metal ions efficiently and the cigarette ignition resistance of the fabric could be improved by further rinsing.
- The total number of ignitions for rectangular and acute angle crevice mockups were similar. The rectangular configuration is the one chosen for most tests of upholstered furniture substrates.

Figure 9. Time/temperature relationships at various locations inside vertical and horizontal PU.

Thermocouples 20 mm inside PU at various distances from crevice line. Bleached Duck/PU/Crevice/Covered Cigarette. Ignition.



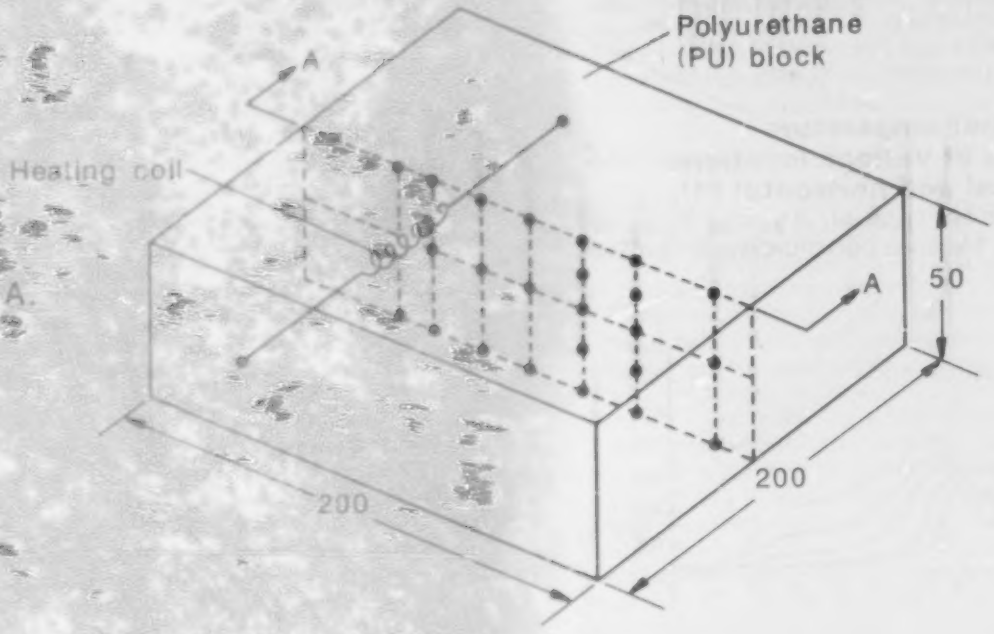
Most other investigators were interested mainly in substrate behavior, with the objective of producing more smolderresistant furniture, rather than defining cigarette/substrate interaction. One laboratory measured fabric surface temperatures with thermocouples in contact with the upholstery fabric surface at various distances from a smoldering cigarette placed on the fabric with the coal end down [47,48]. In this configuration, both peak temperatures and peak widths increased with increasing cotton fabric weight. The smolder propagation rate measured on the fabric surface was inversely related to fabric weight but the mass burning rate remained constant. For a 542 g/m² cotton fabric, the smolder rate varied from 2.7 mm/min for polyurethane foam padding to 4.5 mm/min for glass fiberboard. The following paddings produced results within the 3.5 to 4.0 mm/min range: 25 mm thick polyester batting, polyurethane foam covered with this batting, polyurethane foam covered with flame retarded cotton batting, 50 mm thick polyester batting, and flame retarded cotton batting.

Decreasing the fabric air permeability by a factor of eight by backcoating decreased its smoldering rate by only 14 percent, and decreased the peak temperature by about 50°C [48]. (Washing the fabric in distilled water again prevented ignition.) Other investigators increased air permeability of the cover fabric by cutting slits in it [49]. They found that air permeability changed in this manner did not affect smoldering temperatures measured at the crevice; however, temperature peak width decreased with increasing fabric air permeability. Higher temperature peaks and narrower peak widths were found for a lighter than an heavier fabric; this agrees with Sallo's results [44].

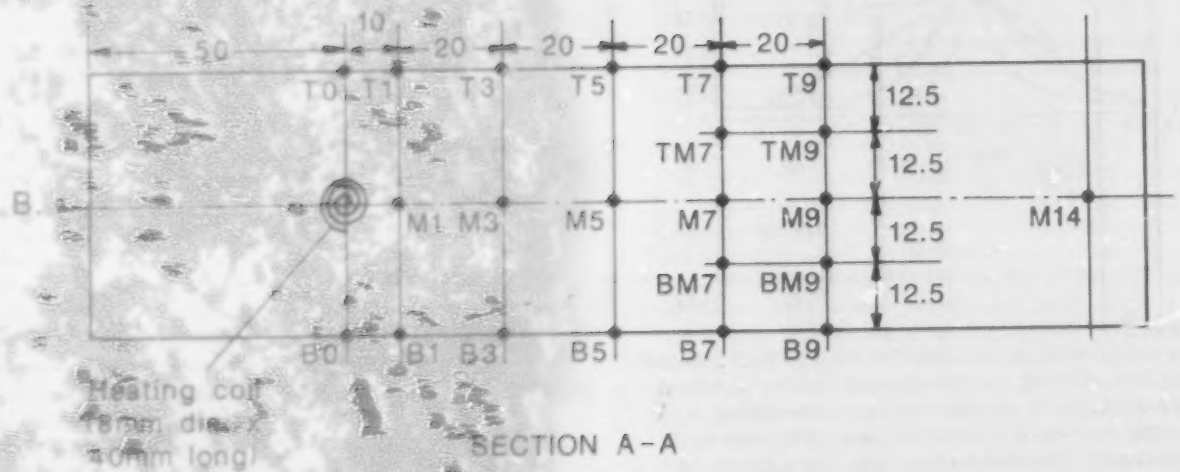
Olsen and Bolinger reported generally higher peak temperatures in the crevice with the fabrics over polyurethane foam than over glass fiberboard [50]. The lowest temperatures and the fastest burn rates were found with cigarettes placed in glass fiberboard crevices, without fabric cover. When the board was covered with fabrics varying in weight from 380 to 530 g/m², Olsen found, unlike most others, no consistent relationship of temperature and burn rate to fabric weight, indicating that fabric finish and other factors dominated in this case. In these glass fiberboard experiments, covered cigarettes produced higher temperatures and wider peaks than uncovered cigarettes. Filter and nonfilter cigarettes of the same brand gave similar results.

The effect of fabric weight and padding material was investigated with thermocouples placed in the crevice and above and below it at the fabric/padding interface of the vertical member of the crevice [46]. The fabric weight was varied by using one, two, or three layers of one of two cotton fabrics. The padding materials were glass fiberboard, polyurethane foam, and cotton batting. With polyurethane foam substrates, and when the fabric mass was low, e.g. one layer, the initial temperatures were higher below the crevice than above it. With three layers, the temperatures were reported to be higher above the crevice. In the case of the cotton batting, temperatures above and below the crevice were similar. These experiments were apparently discontinued when obvious ignition occurred, so the above findings are only for the initial stages of smoldering.

Figure 10. Arrangement for inducing ignition with an electrical heating coil.



All dimensions in millimeters



SECTION A-A

Ignition by Electric Heating Coils [44,45]

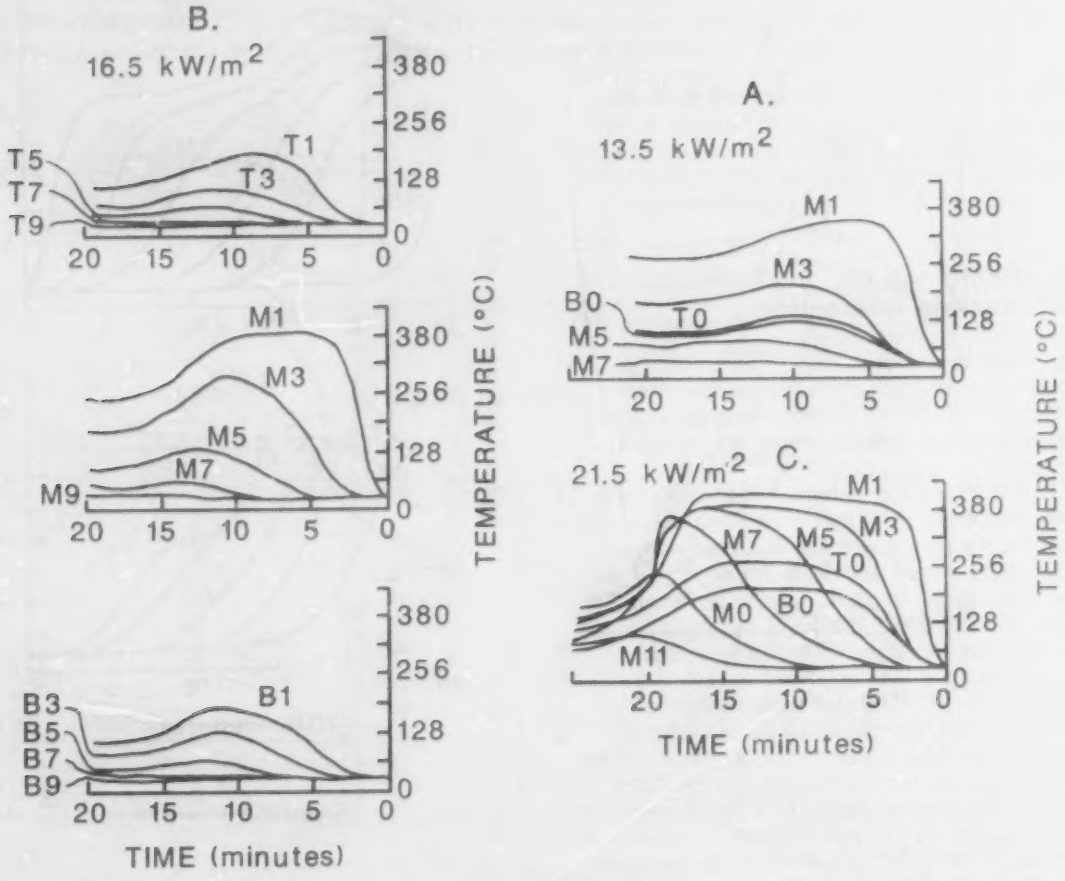
For research purposes, there has been some interest in replacing cigarettes by using better-defined heat sources, such as electric heating coils. In this manner, the ignition of polyurethane foam and other substrates could be more easily modeled. Salig's attempts in this area are described below [44].

Figure 10 shows the experimental arrangement: a 40 mm long, 8 mm diameter electric heating coil was inserted into polyurethane foam blocks covered with fabrics. This is obviously quite different from a cigarette ignition situation but may be appropriate to study smoldering in foam. The smolder wave progress was characterized by thermocouples embedded inside the polyurethane foam. Figure 11 shows the results. A heat flux stated by the author to be about 16 kW/m² initiated smoldering; the method of inferring this flux is not described.

With a dyed cotton duck covering the polyurethane foam, the smoldering continued for about 50 mm and then extinguished; temperatures at the polyurethane foam center were about 380°C and considerably lower at the edges. The smolder self-extinguished even when the heating coil delivered as much as 30 kW/m².

When the polyurethane foam was covered with a heavier diamond weave cotton fabric, both polyurethane foam and fabric smoldered to completion (Figures 12 and 13). Peak temperatures inside the polyurethane foam reached 550°C

Figure 11. Time/temperature relationships inside a fabric-covered PU block, with electric heating coil (various output) embedded.
Dyed Duck/PU/Flat.



and at the top and bottom surfaces, 500°C. These peaks were first reached at the top, then at the bottom, and only then at the center thermocouples. The condition of the substrate 18 minutes into the experiment is shown in Figure 13; Salig stated that the bulging of the fabric ahead of the smolder may be due to expansion of the hot, gaseous combustion products from the polyurethane foam

This experiment indicates the importance of a "critical fabric weight per unit area" in the polyurethane foam ignition process, in this case, with the electric heating coil as the ignition source. The same need for a critical fabric weight per unit area has been found for cigarette ignition sources, as discussed above and in Section 6. It also provides insight into the manner in which gaseous combustion products move inside fabric covered polyurethane foam.

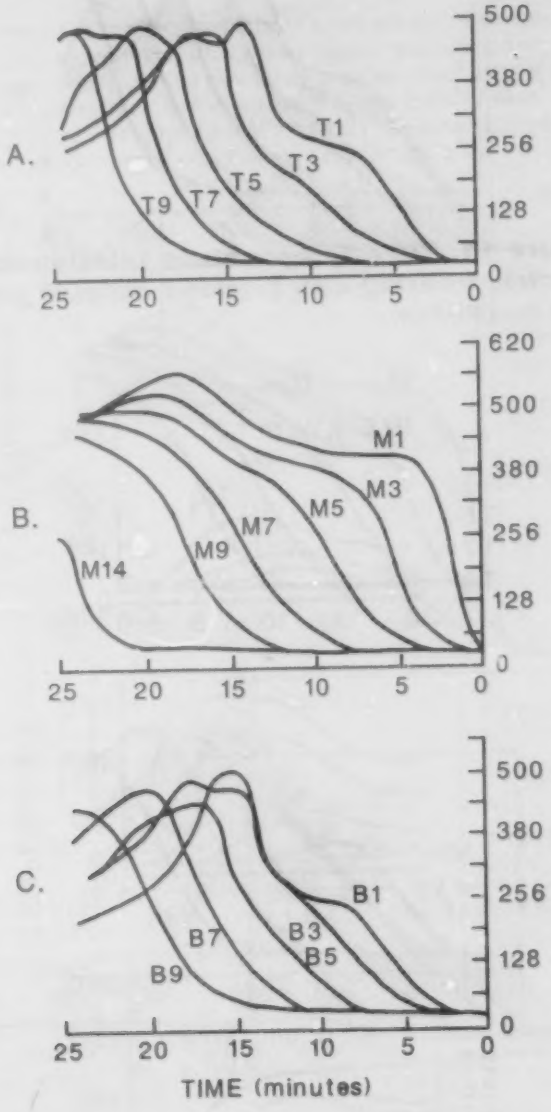
On the other hand, the heating coil experiments clearly point out the differences between a transient and a steady heat source. Thus, the cigarette burn cone with its small area does not ignite polyurethane foam without the intermediate smolder front of critical weight per unit area (medium to heavy) cellulosic fabrics. The static heating coil, with its larger surface, ignited polyurethane foam directly, but the continuation of the smolder process again depended on the fabric cover ignitability. It is also noteworthy that polyurethane foam smolder was reported to be initiated by a coil heat flux of 16 kW/m² while cigarette total heat fluxes were reported to be 40 kW/m² obviously distributed over a much smaller area. While the heating coil experiments are of some modeling interest for polyurethane foam ignition, they seem to be only of limited relevance for the present purposes.

Summary of Findings on Cigarette/Substrate Interaction

No complete model can be constructed from the above survey of observations on cigarette/substrate interactions. However, common threads can be found among these studies, which vary greatly in methodology and purpose.

- Placing a cigarette on a substrate can significantly lower the cigarette temperature and burn rate. These reductions seem to be larger for substrates which subsequently ignite than for those which smolder along with the cigarette but self-extinguish when the cigarette burns out. For example, the peak core temperature of cigarettes burning in air was measured to be about 700°C, of cigarettes burning on substrates which smoldered but self-extinguished, about 600°C, and of those measured during ignition of the substrate, about 500°C. After ignition of the substrate, heat appears to be fed back into the cigarette, raising the core temperature to 600 to 700°C. One could question whether the study of the burning of cigarettes in air is relevant to their behavior on substrates prior to any substrate ignition. Experiments to investigate this phenomenon are presently under way as part of the work under the Cigarette Safety Act.

Figure 12. Time/temperature relationships inside a fabric covered PU block, with electric heating coil (15.5 kW/m²) embedded.
Diamond weave fabric/PU flat. Ignition.



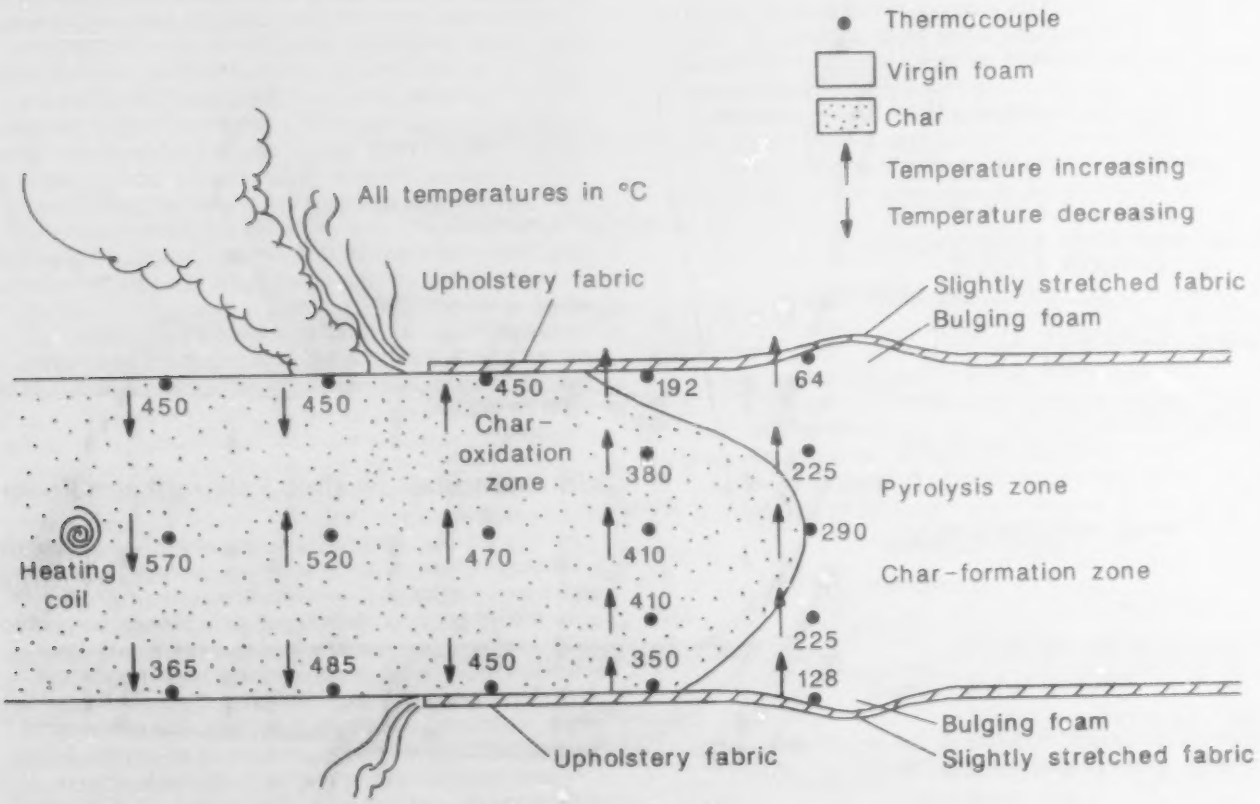
- Cigarette core temperatures reach a plateau during smoldering ignition of the substrate; this appears to be due to competition of the smoldering fabric for available oxygen. Some time after full ignition of the substrate (foam involvement), the cigarette temperature is further increased evidently by feedback from the substrate.

- Cigarettes do not ignite most present-day polyurethane foam substrates unless they are covered by a smolder-prone fabric: it takes the critical weight per unit area of a medium to heavy weight cellulosic or acrylic fabric to obtain polyurethane foam ignition. Cotton batting smolders readily, with and without cellulosic fabrics.

- In crevice ignitions (with the two members at right angles), the temperature inside the horizontal polyurethane foam generally reaches higher peaks earlier than the temperature inside the vertical polyurethane foam slab. The temperature traces inside the polyurethane foam show less pronounced plateaus before ignition than do the traces obtained at the cigarette core.

- Experiments with electric heating coils placed inside the polyurethane foam cannot be substituted for cigarette experiments. While a Japanese worker developed a "standard cigarette" ignition source consisting of a series of small electrical coils heating consecutively, the correlation between results obtained with this apparatus and results with cigarettes of varying ignition propensity was not proven [55].

Figure 13. Schematic drawing of smolder wave in fabric covered PU block, with electric heating coil (15.5 kW/m²) embedded.
Diamond weave fabric/PU/flat. Ignition 18 minutes after start of experiment.



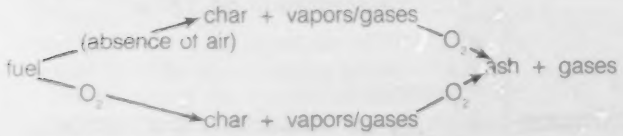
Substrate Smoldering Mechanisms

This section is a brief review of the literature on smoldering of the major padding materials in upholstered items: cellulosic materials and polyurethane foams. While cellulosic padding – cotton batting – ignites readily in contact with a cigarette (because of its favorable packing density and abundance of alkali metal ions), polyurethane foam as currently manufactured needs a smoldering cellulosic fabric cover before it ignites on exposure to a cigarette.

The tobacco column and the paper covering a cigarette are chosen so they will continue to smolder even if not puffed. The paper and tobacco column smolder at the same rate. This smolder spreads readily from cigarettes to medium and heavy weight cellulosic and acrylic fabrics and from them to many commercial padding materials especially cotton batting and polyurethane foam. Certain materials, such as thermoplastic fabrics and batting wool fabrics, and halogen-containing materials (vinyl-coated fabrics, vinyl-vinylidene back-coatings, or polyurethane foam with smolder resistance (SR) treatment) interfere with this transfer. This will be discussed in more detail in Section 6.

Smoldering of Cellulosic Materials

There is a wealth of analyses of cigarette (mostly tobacco column) smoldering behavior, as discussed earlier, and a series of papers analyzing the smoldering behavior of shredded cellulose insulation and polyurethane foam [53,56 59]. No model of smoldering of cotton fabric or batting was found, but the general degradation behavior of cellulosic materials can be approximately described by the following simplified overall reaction scheme:



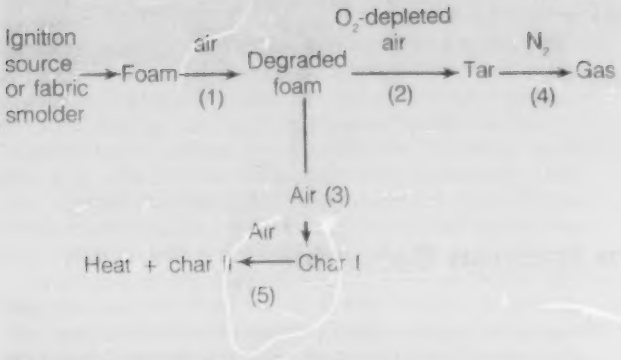
The gases and chars produced by the two different paths may differ in their chemical nature [56]

The above diagram shows that initially there are competing oxidative and pyrolytic reaction pathways; the oxidative pathway can be moderately exothermic (several hundred calories per gram of fuel). Both initial pathways may form a high carbon-containing material (char); the two chars are probably not identical in reactivity or in other properties. These chars are typically somewhat more resistant to oxidation than the initial fuel but ultimately can be completely gasified, releasing a few thousand calories per gram of char. This second oxidation wave can often be visually observed as a glow moving over a previously charred area.

There appear to be no descriptions of basic smoldering experiments with cotton batting or fabrics in the literature. However, in experiments involving shredded cellulosic insulation on a heated plate, smoldering could be initiated at temperatures as low as 220°C, especially in thick smolder beds [57,58]. (This compares with coal temperatures measured in cigarettes between puffs of up to 750°C (Section 3.1), albeit spread over a much smaller area.) Smoldering rate increased with: denser packing of the cellulose insulation, thicker insulation beds, increased oxygen supply, and favorable air current direction. Alkali metal ions have been shown to be smolder promoters in other types of cellulosic materials [48,52,53]. The role of smolder retardants, primarily boric acid, is to interfere with the char oxidation process; they do not necessarily reduce temperatures in the initial smolder wave.

Smoldering of Flexible Polyurethane Foam

Few, present-day, commercial polyurethane foam upholstery or mattress foams could be expected to smolder in contact with burning cigarettes (unless a fabric cover was present) even though such foams vary widely in density, air permeability, chemical composition, etc., e.g., [44,60 61]. Peak smolder temperatures in polyurethane foam were about 400°C or higher, and smolder front progress in those foams which smoldered was about 6 mm/min. The overall foam degradation process during smolder again can be divided into two major competing pathways: formation of non-smoldering tar and formation of smoldering char. A simplified model of the smoldering process in polyurethane foam is given below [62,68]:



Step (1)
The first phase of polyurethane foam pyrolysis involves 10-15 percent weight loss. The product is colored but still has some of the resiliency of the original foam.

Steps (2) and (3)
In the absence of air or when the rate of Step (3) is prohibitively slow, the degraded foam is converted to tar with the loss of extended surface/unit volume essential for smolder. In air, char is formed.

Step (4)
In the absence of air the tar is completely gasified leaving a small residue (1-3 percent) at 500°C.

Step (5)
The black cellular char (which retains much of the foam structure) formed in Step (3) undergoes further oxidation in air and provides heat to drive the smolder wave. If Step (5) is sufficiently fast, then the rate of heat production may be adequate to replace the outside ignition source so that it recedes so far from the external heat source (e.g., smoldering fabric or cigarette) that its own heat generation can no longer overcome heat losses; it will then extinguish.

Two possible approaches to making polyurethane foam smolder resistant have been suggested [63]. One is the use of agents which would interfere with Steps 3 and 5, above, and, if sufficient volatile agent becomes available, also reduce fabric smoldering. The second is promotion of tar formation by weakening the polyol chain and urethane links. The latter, however, may increase flaming combustion.

More specific modeling equations for the smoldering of polyurethane foam in a simplified configuration and reasonable experimental validation are found in [62]. The difficulties caused by the fact that smoldering is very incomplete combustion are discussed. Both conduction and radiation affect the smoldering rate in open structures, such as flexible polyurethane foam. Smolder intensity was found to be governed by oxygen supply rate, but smoldering can proceed at oxygen supply rates as low as 5 percent of the stoichiometric rate of oxygen supply to the smolder reaction zone. The threshold oxygen concentrations at which self-extinguishment continued smoldering, or transition to flaming occurs were established for three polyurethane foams [61]. This work was performed with an electrical heating coil embedded in the substrate rather than with a cigarette on the sample surface. Such embedded heating coils appear to give results different from cigarettes, and seem to lead to faster transition to flaming than cigarette-induced smoldering as discussed earlier [44].

Most polyurethane foam formulation variables had little effect on smoldering [63]. A report on an interlaboratory test to establish reproducibility of results obtained with a "standard" polyurethane foam claims that there were no differences between specimens sampled along the length and from top to bottom of a polyurethane foam bun (a production lot) [65]. A significant effect of breathability of the polyurethane foam was found, and it was suggested that samples be flexed before testing; this increases breathability and would simulate conditions in actual use. On the other hand, experience has shown that it is difficult to produce a "standard" foam which, combined with a "standard" fabric, gives reproducible ignition or non-ignition results [69]. Among the reasons may be that foams are not quality controlled with respect to cigarette ignition resistance, but rather to obtain approximate uniformity of density and resiliency. The formulation of flexible polyurethane foam is not considered a precise art.

Some flame retardants increased others suppressed smoldering. Several studies describe improvement in smoldering resistance of fabric/polyurethane foam mockups due to use of proprietary smolder and flame retardants, e.g., [66-68,72,74].

Cigarette Ignition Behavior

Cigarette Ignition Behavior of Soft Furnishings

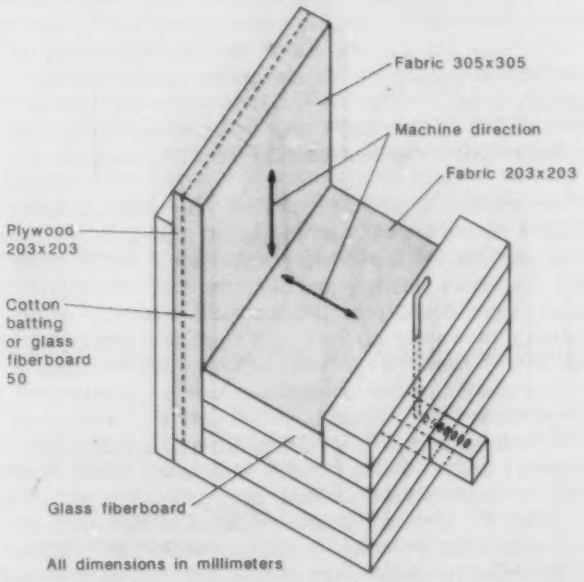
The papers discussed in this section reported primarily ignition or non-ignition of the substrates [54.69.108]; papers in which time/temperature relationships in the substrate or cigarette were explored were discussed earlier [44 51]. The basic configuration of the mini-mockup shown in Figure 14 was used in most of the evaluations of upholstered furniture substrates discussed in this section. The test methods used for the evaluation of the cigarette ignition resistance of soft furnishings are listed in Appendix A.

A discussion of the cigarette ignition behavior of soft furnishings is given in Sections 3.1, 3.2 and 5 of [9]. An earlier bibliography of papers on cigarette and flame ignition of upholstered furniture contains 149 references [75]. Two general discussions of cigarette ignition resistance summarize the state of the art up to 1984 [76-77]. The results are based on experiments with mini-mockups, mockups, or full-scale furniture. No papers on ignition resistance of fabrics or padding materials alone are included because there is ample literature showing that the ignition behavior of the individual mockup components does not provide reliable ignition information on the material combinations [22,69]. A substantial part of the experimental work on cigarette ignition was performed at the California Bureau of Home Furnishings [60,79,80,91-97,105]. A discussion of the relevance of bench-scale mockup tests to cigarette ignition behavior of full size furniture is part of an ongoing study under the Cigarette Safety Act, and will be discussed in a future report.

Table 6 summarizes the findings of many such studies. The materials in the table are listed from top to bottom in the approximate order of decreasing cigarette ignition resistance. In many cases, there is considerable overlap between the characteristics of materials listed near each other, depending on such factors as smolder retardant finish in fabrics or padding, polyurethane foam variables, alkali metal ion content, fabric finish and backcoating.

It should be emphasized that some materials which have good cigarette ignition resistance do not necessarily have good small flame ignition resistance and *vice versa*. For example, substrates covered with thermoplastic fabrics tend to resist cigarette ignition because some of the heat transferred to the fabric is absorbed by fabric melting. However,

Figure 14. Mini-Mockup Test Arrangement for Cigarette Ignition.
Cigarettes are generally placed into the crevice.



the thermoplastics shrink, curl and melt upon contact with an open flame and expose the padding. On the other hand, cigarettes induce smoldering in medium to heavy weight cellulosic fabrics, with consequent heat transfer to the padding, but in contact with a small flame cellulosic fabrics char and, until the char breaks, protect the padding. Similarly, some flame retardants for polyurethane foam reduce resistance to smoldering, while others improve both flame and cigarette ignition behavior [60].

To prevent ignition by cigarettes, it is not necessary to use only the materials listed on top of each column in table 6. For instance, the combination of a light weight thermoplastic fabric with polyurethane foam may not ignite. Similarly, the combination of a medium weight cellulosic fabric with a layer of polyester batting enveloping a polyurethane foam slab may not ignite. Many wool and medium-to-heavy PVC-coated fabrics with flame retarded or ordinary polyurethane foam or mixed (thermoplastic/cellulosic fiber) batting have satisfactory cigarette ignition resistance. Material combinations which are, for all practical purposes cigarette ignition resistant in a crevice configuration with the cigarette covered (the worst case conditions), can be chosen on the basis of a few trials in a qualified laboratory. The number of such trials can be kept small by using the information from the table.

Tables 7 and 8 are examples of data on which the following discussion will be based. Table 7 compares results obtained with a number of fabrics combined with untreated and flame retarded polyurethane foam [90]. Table 8 summarizes two studies by the California Bureau of Home Furnishings [91,93]. In one, conducted in 1976 over 80 upholstery fabrics popular in California at that time were tested over 10 padding materials each in the mini-mockup configuration. The other study covered 171 commercial furniture items sampled in 1981-82 to check compliance with the California standard.

Below is a discussion of the effect of the individual substrate components on cigarette ignition. Because of the interaction between such components, there is a certain amount of redundancy.

Effect of Fabrics

Fiber content and weight. Many studies indicate that increasing the amount of cellulosic materials (cotton rayon, linen, hemp in fabrics, cotton in batting) in the substrate decreases cigarette ignition resistance. Increasing the amount of thermoplastics (nylon, polyester, and polyolefin in fabrics and thermoplastic fibers usually polyester in batting) increases the cigarette ignition resistance.

The highest cigarette ignition resistance is obtained with wool and PVC-coated fabrics [22,76,82,90]; their efficacy increases with fabric mass per unit area (fabric weight) and, in the case of PVC, thickness of coating. Blending of thermoplastic fibers with cellulosic fibers increases cigarette ignition resistance over that of pure cellulosic fabrics; the data shown in Table 8 imply that fabrics with 20 to 50 percent thermoplastic content rarely ignite from cigarettes [91-96].

Table 6. Upholstered Furniture Components Listed in Approximate Order of Descending Cigarette Ignition Resistance [44-51,54,69-108]

Resistance	Cover Fabric[a,b]	Padding	Interliners	Welt Cords	Construction Parameters
HIGHER	Wool, PVC	Specialty foams[d]	Aluminized fabrics	Aluminized	Flat areas
	Heavy thermoplastics	Polyester batting	Neoprene sheets	PVC	Flat areas near welt cord
			Vinyl coated glass fab.	Thermoplastics	
	Cellulose/thermoplastics blends (depending on thermoplastic percentages)	PU	Novoloid felts	SR treated cellulosics	Tufts
		SR cellulosic batting	Thermoplastic fabrics	Cellulosics	Crevices
	Light thermoplastics	Untreated PU	Cellulosic fabrics		
	Light cellulosics[c]	Mixed fiber batting			
LOWER	Heavy cellulosics	Cellulosic batting			

[a]Data on the behavior of acrylic fabrics are sparse, but these fabrics seem to behave more like cellulosics than thermoplastics.
[b]Fabrics here include woven, knitted, and nonwoven structures.
[c]There is probably no effect of cellulosic fabric weight when it is used with cotton batting.
[d]Includes here neoprene and combustion modified, high resiliency (CMHR) PU foams.
SR – smolder resistant

However, no systematic study of such blends to optimize the retention of the appearance and feel of cellulosic fabrics, as well as cigarette ignition resistance, has been undertaken. Possible variables in such a study would be: location of the thermoplastic fibers—e.g., by placing them in the filling in weaves where such filling appears mostly on the surface; amounts needed in intimate yarn blends to obtain cigarette ignition resistance; type of thermoplastic—nylon, olefin, polypropylene, etc.

Finish: Permanent (non-water-soluble) flame retardant treatments of fabrics do not necessarily increase cigarette ignition resistance and can, in fact, exacerbate the smolder tendency of cellulosic fabrics [91]. Treatment of cellulosic fabrics and cotton batting with some non-permanent materials, e.g., a combination of borax and boric acid, can increase both flame and cigarette ignition resistance [47,93,98-103]. Higher concentrations are often needed for cigarette ignition resistance than for flame resistance. Such treatments can affect the color and feel of fabrics but have been recommended for batting for prison mattresses, for example [47,101].

Proprietary spray products claimed to make possible reasonable cigarette ignition resistance and flame ignition resistance of upholstered items by retrofit have been promoted. Tests with three such sprays indicated that the needed amount of spray is larger than one would expect a consumer to apply, and that it caused the fabrics to appear discolored and harsh to the hand [107].

Most commercial backcoatings either did not affect the cigarette ignition resistance or else seemed to improve it [79,85,91,93,97,106]. A vinyl vinylidene latex backcoating and certain organophosphorus flame retardants added to the backcoating have been reported to improve furniture fabric cigarette ignition resistance [104,106].

Table 7. Typical Cigarette Ignition Test Results [90]

Fabric Structure[a]	Fabric Weight (g/m^2)	Fabric[b] Burn Time (s)	PU[c] Foam Type	Cigarette[d] Ignition Pass/Fail
100% cotton chemille	355	13	NFR FR	F F
56 cot + vis/5pe/39 acr plush	400	26	NFR FR	P P
52 linen/48 cot panama	430	41	NFR FR	F F
54 nyl/32FR vis/14 pe plush	400	47	NFR FR	P P
34 wool/52 vis/14 nylon panama	450	56	NFR FR	P P
65 wool/35 FR vis twill	540	SE	NFR FR	P P
52 wool/27 cot/21 nylon twill	575	SE	NFR FR	P P
100 wool reps	375	SE	NFR FR	P
PVA PVC twill	475	SE	NFR FR	P
87 cot/13 FR vis.	200	SE	NFR FR	F P

[a] cot - cotton, vis - viscose, acr - acrylic, pe - polyester
[b] Modified CS-191 Test (flame ignition), SE - self-extinguishing
[c] PU: untreated (NFR) 30 kg/m^3, flame retarded (FR) 33 kg/m^3
[d] F - fail, P - pass

Contamination of cellulosic fabrics and battings. The presence of alkali metal ions, such as sodium and potassium, decreases cigarette ignition resistance [19,48,52,53]. This important effect has thus far hardly been considered by industry in fabric design and finishing.

Alkali metal ions are always present in unscoured cotton. On finished fabrics, they may be present as residual detergents, softeners, dyes, or dye auxiliaries. Rinsing such fabrics in clean water or laundering often causes dramatic improvements in cigarette ignition resistance [19,45,48,52]. In spite of the publication of these results little seems to be done by industry to remove these contaminants. A simple method to evaluate whether residual fabric finish lowers the cigarette ignition resistance of fabrics is described in Section 3.2.2 [19].

Since perspiration and other dirt likely to be deposited on soft furnishings contain alkali metal ions furniture may become more ignitable with age. However a study of the effect of use and aging on the cigarette ignition resistance of chair cushions is not conclusive on this point [84].

Tension. No systematic study of the effect of fabric tension on cigarette ignition resistance is available, but a summary of personal observations from our laboratories can be reported. When tension is low, as in old furniture or certain styles, air layers may form between the fabric and the padding, and cigarette ignition will be determined entirely by the fabric. With higher tension, intimate contact between the fabric and padding is achieved and the padding can act either as a heat sink (e.g., smolder resistant polyurethane foam), absorb heat during melting (polyester batting), or smolder along with smoldering fabrics (cellulosic batting).

Miscellaneous construction factors. The effect of fabric weight has already been discussed. No systematic studies of the effect of other fabric parameters, such as weave, yarn size and density, pile vs. non-pile, etc., have been carried out. In grass clippings and foam, denser packing has been shown to increase the smolder tendency [16,17,61,109]. This indicates that not only weight but dense packing of fibers and other cellulosic materials promotes smoldering. Lowering air permeability has been reported to increase cigarette ignition resistance, but in some of these experiments, this was achieved by applying latex backcoatings This process introduces extraneous materials and increases the weight [48]. Increasing the air permeability by making slits in the fabric increased the smoldering rate, but not the smoldering temperature and total char areas [49].

Sheets and blankets can increase the probability of mattress ignition when they are placed on the top of a burning cigarette. These items generally do not ignite from cigarettes [22,82].

Effect of Padding Material

The relative effect of padding material on cigarette ignition resistance is summarized in Table 6. Smolder resistant neoprene and the combustion modified, high resiliency (CMHR) polyurethane foams rank high. Polyester batting absorbs heat as it melts. Many flame retarded treatments of polyurethane foams used some years ago did little to improve smolder resistance or even reduced it. In the last few years, mainly in response to the California requirements [110], flame retardant treatments which improve both smolder and flame resistance of polyurethane foam have been marketed. The smolder resistance of the boric acid treated cotton batting depends on the boric acid concentration; some of this can be lost in handling the batting since the material does not stick well to the fibers [102,103]. Untreated cellulosic batting smolders readily [22,54,60,69-71,88-101,110].

Effect of Interliner or Barrier Materials

The UFAC program [54] requires that all cover fabrics be tested, and those which are more ignition prone (called Class II by UFAC) must be used with a barrier material. The most common barrier material is polyester batting. However, many fabrics, especially heavy cellulosics, ignite even with such polyester barriers [69,79]. On the other hand, the use of aluminized barrier or interliner materials between the cover fabric and padding was found to be very effective in increasing cigarette ignition resistance [22,44,45,71].

UFAC also introduced a test for "interior fabrics," fabrics often placed between the cover fabric and the padding [54]. The test generally fails cellulosic fabrics but passes thermoplastic woven and nonwoven fabrics. Other interliners which increase cigarette ignition resistance are neoprene and CMHR polyurethane foam sheets.

Effect of Welt Cord

The cigarette ignition resistance of crevices and cushion edges can be enhanced or reduced by the presence of a welt cord, depending on its type [54,69-71]. The cigarette ignition resistance is reduced if the welt cord contains a cellulosic material, usually in the form of twisted paper or cotton cords. Aluminum foil twisted into welt cords has been shown to have better cigarette ignition resistance than untreated and flame retarded cellulosic welt cords [78]. UFAC has recently upgraded its welt cord standard to eliminate the latter [54]. Some thermoplastic and PVC welt cords also conform to the upgraded welt cord standard.

In addition to the direct effect of the welt cord, it is often enclosed in a strip of fabric. This increases the fabric mass in the crevice. In the case of cellulosic fabrics, this reduces cigarette ignition resistance, and in the case of thermoplastics, it may increase it [54,69].

Effect of Furniture Geometry

For any combination of fabric and padding material, cigarette ignition resistance is better in the flat areas than in the crevices [6,19,23,44,45,69,77]. Several factors may contribute to the greater hazard in the crevice: re-radiation of heat from two, rather than one, surfaces; a chimney effect in the crevice under the cigarette [22,44]; and, in the case

Table 8. Cigarette Ignition Resistance of Typical Fabric/Padding material Combinations [91-92]

	Percent of Fabrics Igniting		
	100% Cellulosics	Cellulosic/ Thermoplastic Blends	100% Thermoplastic
A. Mini-mockup results (1977) padding materials[a]			
Batting:			
100% cotton			
Untreated	100	82	9
FR treated	76	43	0
70/30 cotton/polyester	79	32	0
100% polyester			
Non-resinated	33	7	0
Resinated	19	4	0
Foam:			
Polyurethane			
Untreated	41	25	0
FR treated 1	86	54	0
FR treated 2	38	25	0
High resiliency	83	57	0
Neoprene interliner over cotton batting	19	14	0
Glass fiberboard	100	54	0
B. Results on 171 furniture items (1983) [225][b]			
fabric weight	<270 g/m²: 67	≥70% cell: 6	6
fabric weight	≥270 g/m²: 95	<70% cell: 82	

[a]Filling material specifications:

Materials	Density, kg/m³
1. Batting:	
100% cotton, untreated	38
FR cotton (12-15% boric acid)	38
70/30 cotton polyester, bonded	37
100% polyester, resinated (28% acrylic resin)	8
100% polyester, non-resinated (with polyester scrim)	8
2. Foam:	
Untreated PU	20
FR PU 1 (antimony trioxide and PVC)	37
FR PU 2 (brominated biphenyl)	32
High resiliency PU (brominated organophosphate)	42
3. Neoprene interliner: 5 mm thick with cotton scrim backing	950 g/m²

[b]Various filling materials.

of cellulosic fabrics, an increase in the mass of cellulose because of multiple seams at pillow edges. Crevices can be rectangular, or, if the top of the cushion is rounded or pulled away from the vertical surface, form an acute angle; Ihrig, *et al.*, have shown that there is little, if any, differeance in the cigarette ignition resistance of these two crevice configurations [19]. Tufted areas also tend to have lower cigarette ignition resistance than flat areas and are usually tested separately, as are areas near the welt cord of flat cushions [22].

Cigarette Ignition Behavior of Wildlife Materials

Some of the early investigations of the propensity of cigarettes to ignite materials were conducted on wildlife materials. The effect of wind velocity and direction and of the ambient conditions was also more intensely studied on these materials than on soft furnishings. A summary of these studies is presented because of the physical similarity of the ignition process and the cellulosic nature of the wildlife fuels.

Wildlife material, including compacted conifer needles, grass, and punk wood can be ignited by cigarettes [16,17,23,25,109,111]. Conditions which increase the probability of such ignition are: dense packing of material (e.g., 100 kg/m^3 for dried grass clippings), high ambient temperature and low humidity, and modest winds. Especially in the direction of the burn cone travel on the cigarette. Especially in winds of 4.8-6.4 km/hr, these substrates seem to burst into flames rather rapidly, without lengthy smoldering periods. The optimum wind velocity for ignition by cigars was higher, about 12 km/hr.

In the late 1920's, the National Bureau of Standards conducted an investigation (in response to Congressional interest in reducing cigarette-initiated wildlife fires) into the feasibility of reducing the ignition propensity of cigarettes [16,17]. A frequency distribution of the length of discarded cigarette butts was established. The most frequent length was 33 mm, and two thirds of the butts were under 38 mm. It was concluded that if cigarettes could be treated so as to not ignite substrates while burning over this length, the problem would be solved. A number of treatments were suggested, including borax, borax/boric acid, and sodium silicate, as well as additional layers of paper or cork at the butt end; the latter appeared promising. Fortunately, the use of asbestos paper for this purpose was shown to be ineffective.

Cigarette Ignition of Garments

Garment fires are often blamed on cigarette ignition. However, two investigators established that the fabrics used in such items generally do not ignite from exposure to cigarettes [26,112]. Improperly used matches or lighters are more likely ignition sources in such cases.

Relative Ignition Propensity of Cigarettes

A number of laboratories have conducted experiments to determine the relative ignition propensity of commercial cigarette packings [5,7,8,10-17]. Several packings with a somewhat lower ignition propensity than most others were identified in the U.S. as well as Japan. Such identification can be made on substrates which have borderline cigarette ignition resistance, e.g., crevices formed by the California or UFAC standard fabric and UFAC standard or similar polyurethane foam types [11,13]. The majority of upholstery substrates would, however, either not ignite with any or ignite with all commercial cigarette packings, because of the small range of ignition propensity of present, commercial cigarette packings.

In one study, a number of fabrics were used so that one fabric ignited with all test cigarettes one fabric with none and several with some but not all cigarette packings, allowing a ranking of the ignition propensity of the cigarettes [7].

The same cigarette packings were also placed for 1, 2, or more minutes on flat areas of the substrates of varying cigarette ignition resistance and then removed [7]. If the substrate still smoldered 10 minutes after the removal of the cigarette, ignition was recorded. Thus the propensity of cigarettes to ignite substrates could be defined both by the number of substrates a given cigarette ignited and the time it took to ignite any specific substrate. Times to ignition varied from 2 to 7 minutes; Salig found ignition times of 1.5 minutes for low cigarette ignition resistance substrates [44].

Two means of quantifying the propensity of cigarettes to ignite substrates have been suggested. One is to place the cigarettes on mini-mockups made from standard fabric and foam as in the California upholstered furniture test [110] (Figure 2), and measure the mass loss rate. The other consists of placing the cigarette on a piece of α-cellulose chromatographic analysis paper and again measuring the mass loss rate [7]. The latter method was proposed in the belief that the chromatography paper was more reproducible than fabric and polyurethane foam which have shown cigarette ignition resistance variations even in so-called "standard" materials [69]. This concept was critically discussed in [113]. Ihrig, *et al.*, found a positive correlation between cigarette ignition propensity of four experimental cigarettes and cal/cigarette of the cigarettes in air [19].

The studies of relative ignition propensity of commercial cigarette packings can be summarized as follows:

1. Most cigarette packings investigated have similar ignition propensity. However, a few packings have been found to have somewhat lower ignition propensity. This was found for a variety of upholstered substrates, in flat areas and crevices varying in fabrics and padding materials [6,7,10,11,13-15], in mattresses [8,12], and in wildlife material [7,16,17].

2. Propensity to ignite did not correlate with burning rate or burn cone temperatures of the cigarettes [7].

3. While the commercially available cigarettes did not make it possible to conduct an experiment in which such parameters were varied systematically, it appears that lowering the fuel content, by reducing packing density and by reducing the diameter may lower the ignition propensity [6,7]. Making the burn time of cigarettes shorter, by either making the tobacco column shorter or lowering the packing density (which increases linear burn rate) would obviously reduce the time during which a smoker may become sleepy and inadvertently drop the cigarette.

4. The differences in ignition propensity of the commercial cigarette packings tested are small in the context of the cigarette ignition resistance of the total population of soft furnishings in American homes which may be subject to contact with inadvertently dropped cigarettes. Perhaps one half of this population – a rough guess indeed – may not ignite from any cigarette. This would include mattresses produced since 1973, when the U.S mattress standard started to be enforced [114], as well as most furniture made to the principles outlined above in Section 6. Another large portion may ignite with all commercially available cigarettes. The percentage of soft furnishing substrates which ignites with some but not all present day commercial cigarette packings is probably quite low.

Conclusions

The literature pertinent to ignition of soft furnishings and of wildlife materials by smoldering cigarettes was critically reviewed, with the objective of presenting as much background material as possible which may assist in the consideration of cigarettes with lower ignition propensity. Material was included in this report which may be relevant to construction of a model for cigarette ignition of soft furnishings, especially information on the burning behavior of cigarettes.

Other material included discusses the cigarette ignition resistance of upholstered furniture and mattresses. While there is a large amount of literature in those two fields, the area of most direct interest—how cigarette parameters affect their ignition propensity—had not been well-studied, and much more needs to be done.

Perhaps the most important finding was that the smoldering behavior of cigarettes on substrates is different from that of cigarettes burning in air. Compared to the temperatures observed in free burning (in air), core temperatures of cigarettes before full ignition of fabric and polyurethane foam ignition were distinctly lower. However, these temperatures were maintained over longer periods. After both the cellulosic cover fabric and the polyurethane foam padding ignited, heat feedback from the smoldering substrate increased the observed cigarette core temperature.

Studies of the interaction of cigarettes and igniting substrates have been performed with commercial cigarettes. It was found that most of the cigarettes used in these experiments behaved quite similarly; however, a few cigarette packings with somewhat lower ignition propensity on certain fabric/padding combinations were found in these studies. The specific factors which led to the lower ignition propensity have not yet been clearly established.

Acknowledgements

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Appendix A
Test Methods for Determining Cigarette Ignition Resistance of Soft Furnishings

Code of Federal Regulations, Part 1633, Proposed Standards for the Flammability (Cigarette Ignition of Upholstered Furniture (PFF 6-81), U.S. Consumer Product Safety Commission (1981).

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Standard Methods of Tests and Classification System of Cigarette Ignition Resistance of Components of Upholstered Furniture. (NFPA 260 A) 1986 Standard Method of Test for Determining Resistance of Mock-up Upholstered Furniture Material Assemblies to Ignition by Smoldering Ciragettes (NFPA 260 B), National Fire Protection Association (NFPA) (1983).

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Irish Standard Specification, Requirement for Smolder and Flame Resistant Upholstery, I.S. 244; 1980, Institute for Industrial Research and Standards, Dublin (1980).

Nordtest Fire 014, NordTest, SF 00340, Helsingfors 34, Finland.

Furniture Upholstered Seating Method of Test for the Ignitability (by a Smoldering Cigarette), Svensk Standard SS 83 91 30, SIS Standardiseringgrupp, Stockholm Sweden.

DOE/PSA Fire Retardant Specification, No. 3: Fire Barrier Standards for Upholstery (Seating and Bedding); No. 4: (Composite Upholstery Ignition Standard (Seating and Bedding); No. 5: Flammability of Beds and Bedding; No. 6: Ignition Standard for Seating. Department of the Environment/Public Service Agency, London (Apr. 1978).

Code of Federal Regulations, 16 CFR, Part 1632, Standard for the Flammability of Mattress (and Mattress Pads), FF 4-72 (1983).

Method of Test for the Combustion Resistance of Mattress; Cigarette Test. Canadian Government Specification Board, Ottawa, Ont. Canada, No. 27.7 (1977).

Behavior of mattresses in Fire: Cigarette Test. Bulletin official des Services des Prix, Annexe a la Recommendation No. D1-78 Direction General de la Concurrence et de la Confirmation, Paris Dec. 1978).

Appendix B
List of Patents

Most of these patents were furnished by Dr. P. H. Leake of the American Tobacco Company and Dr. A. W. Spears, III of Lorillard, A Division of Loews Theaters, Inc. A few additional patents were found by searching World Patents. This list is believed to be reasonably complete.

A. U.S. PATENTS

Number	Title	Date
253,841	Cigar and Cigarette Wrapper	2/21/1882
1,020,864	Cigarette	3/19/1912
1,211,071	Ash Retaining Cigarette and the Like	1/2/1917
1,517,142	Cigarette Holder and Extinguisher	11/25/1924
1,555,320	Cigarette	9/29/1925
1,581,451	Fire Safe Cigarette	4/20/1926
1,605,059	Cigarette	11/2/1926
1,666,062	Cigarette	4/17/1928
1,726,737	Smoking Article	9/3/1929
1,744,615	Cigarette	1/21/1930
1,770,616	Cigarette	7/15/1930
1,798,537	Cigarette	3/31/1931
1,821,159	Attachment for Cigarettes	9/1/1931
1,879,128	Cigarette	9/27/1932
1,905,416	Cigarette	4/25/1933
1,996,002	Decreasing Inflammability of Cigarettes	3/25/1933
1,999,222	Cigarette	4/30/1935
2,013,508	Difficultly Flammable Cigarette Wrapper	9/3/1935
101,312	Design for a Combined Cigarette Holder, Ashtray, and Extinguisher (Design Pat.)	9/22/1936
2,049,320	Cigarette	7/28/1936
2,098,619	Cigarette	11/9/1937
2,134,213	Protective Cigarette Holder	10/25/1938
2,147,889	Processing of Tissue or Paper and the Product Obtained Thereby	2/21/1939
2,246,929	Cigarette	6/24/1941
2,307,088	Cigarette	1/5/1943
2,327,991	Cigar and Cigarette	8/31/1943
2,329,927	Method of and Composition for Treating Cigarettes, Cigarette Paper and Tobacco	9/21/1943
2,335,432	Cigarette Extinguisher	11/30/1943
2,526,572	Combination Smoker's Mouthpiece and Ash Receptacle	10/17/1950
2,536,900	Snuffer	1/2/1951
2,547,119	Cigarette	4/3/1951
2,607,353	Cigarette Holder	8/19/1952
2,625,163	Safety Cigarette Holder	1/13/1953
2,666,437	Cigarette Extinguisher	1/19/1954
2,679,251	Safety Cigarette Holder and Cleaner	5/25/1954

A. U.S. PATENTS (cont'd)

Number	Title	Date
2,701,571	Device for Smoking Cigarettes	2/8/1955
2,718,889	Heat Absorbing and Transferring Band for Cigarettes	9/27/1955
2,746,890	Cigarette Device	5/22/1956
2,754,828	Cigarette and Method of Making the Same	7/17/1956
2,786,471	Cigarettes	3/26/1957
2,788,005	Cigarette Smoking Device	4/9/1957
2,827,059	Cigarette Holder	3/18/1958
2,890,704	Cigarette	6/16/1959
2,900,987	Ash-Retaining Jacket for a Cigarette	8/25/1959
2,932,301	Safety Cigarette Holder Made from Perforated Paper and Metal Foil 2,965,107	4/12/1960
	Snuffer	Cigarette 12/20/1960
2,998,012	Cigarette and Wrapper Therefor	8/29/1961
3,030,963	Cigarette Construction	4/24/1962
3,034,932	Tobacco Composition	5/15/1962
3,081,776	Cigarette Coal Anchor for Filter Cigarette 3,091,243	3/19/1963
	Self-Extinguishing Cigarette	5/28/1963
3,102,543	Safety Tip Cigarette	9/3/1963
3,165,105	Ash-Retaining Safety Cigarette	1/12/1965
3,183,914	Cigarette	5/18/1965
3,220,418	Cigarette	11/30/1965
3,276,453	Cigarette Construction	10/4/1966
3,288,145	Tobacco Article	11/29/1966
3,318,314	Apparatus for Producing a Continuous Tobacco Rod	5/9/1967
3,528,432	Cigarette or the Like Having Combustion Stop	9/15/1970
3,632,384	Method of Making Cigarette Paper with Ash-Retaining Means	1/4/1972
3,702,117	Cigarette	11/7/1972
3,736,940	Cigarette with Ash-Retaining Means	6/5/1973
3,821,958	Fire-Proof and Ash-Proof Cigarette	7/2/1974
3,886,954	Fire Safety Cigarette	6/3/1975
3,916,916	Shield for Cigarettes and Cigars	11/4/1975
3,977,416	Cigarette with a Snuffer	8/31/1976
3,985,143	Self Extinguishing Cigarette	10/12/1976
4,027,680	Safety Cigarette Holder and Ash Retaining Device	6/7/1977
4,034,767	Cigarette Holder	7/12/1977
4,044,776	Cigarettes	8/30/1977
4,091,821	Smoking Article Having an Ignition Suppression Disk	5/30/1978
4,121,597	Filtering Pipe with Extinguisher for Cigarettes	10/24/1978
4,146,040	Cigarettes	3/27/1979
4,187,862	Treatment of Cigarette Paper	2/12/1980

Number	Title	Date
4,230,131	Self-Extinguishing Cigarettes	10/28/1980
4,241,742	Ashtray to Control Burning Rate of Cigarette	12/30/1980
4,303,084	Self-Extinguishing Cigarettes	12/1/1981
4,386,616	Cigarette Tube	6/7/1983
4,413,638	Safety Cigarette Bottle	11/8/1983
4,436,101	Self-Extinguishing Cigar or Cigarette	3/13/1984
4,452,259	Smoking Articles Having a Reduced Free Burn Time	6/5/1984
4,453,533	Treatment of Cigarette Paper	6/12/1984
4,480,650	Coated Self-Extinguished Cigarette	11/6/1984
4,489,738	Self-Extinguishing Cigarettes	12/25/1984
4,491,139	Self-Igniting Smoking Device	1/1/1985
4,521,333	Intumescent Silicates Having Improved Stability	6/24/1986
4,582,073	Self-Extinguishing Cigarettes	8/17/1984
4,570,645	Safety Holder for Cigarettes	2/18/1986
4570,646	Method and Apparatus for Smoking	2/18/1986
4,570,650	Self-Extinguishing Cigarette	2/18/1986
4,572,217	Fire-Safe Cigarette Holder System	2/25/1986
4,582,073	Check Valve Type Cigarette Mouthpiece	4/15/1986
4,585,014	Fire Inhibiting Tubular Safety Shield for a Cigarette Type Smoking Device and Combination Thereof	4/29/1986
4,615,345	Self-Extinguishing Cigarettes	10/7/1986
06/627,710	Reduced Ignition Proclivity Smoking Article Wrapper and Smoking Article NOTE: This is an application	7/11/1986
06/877,803	Smoking Articles NOTE: This is an application	6/24/1986
7045	Wrapper Constructions for Self-Extinguishing and Reduced Ignition Proclivity Smoking Articles NOTE: This is an application	9/26/1986

B. FOREIGN PATENT

Country	Number	Title	Date
Australia	149,216	Improvements in Cigarettes with Filter Plugs or Other Internal Mouthpieces and Methods and Machinery Used in Their Production	1/24/1951
Belgium	659,839	Improved Cigarette	6/16/1965
France	1,040,981	Safety Devices for the Use of Smokers	10/20/1953
France	1,402,088	Smoking Article	5/3/1965
France	1,446,152	Device for Automatically Extinguishing the Burning Ends of Cigarettes and Such	7/6/1966
France	1,517,283	Safety Process Designed to Prevent and Reduce Damages and All Types of Accidents Caused by the Ashes from a Burning Cigarette	3/15/1968
France	1,537,845	Cigarette with Ash-Retaining Paper and Process for Its Manufacture	8/30/1968
France	1,553,960	Automatic Cigarette Extinguishing	1/17/1969
France	1,560,360	Cigarette Improvements	3/21/1969
France	1,590,223	Process and Means for the Manufacture of Cigarette Papers with a Perforated Flameproof Network; Papers and Cigarettes Obtained by These Processes and Means	5/22/1970
France	2,044,336	Process and Means for the Manufacture of Cigarette Papers with a Perforated Flameproof Network; Papers and Cigarettes Obtained by These Processes and Means	2/19/1971
France	2,177,138	Process for the Manufacture of Cigarette Paper with a Perforated Fireproof Network	11/2/1973
Germany	531,768	Medium for Extinguishing the Remainder of a Cigarette	8/14/1931
Germany	549,936	Extinguishing Cigarette	5/3/1932
Germany	608,407	Cigarette	1/23/1935
Germany	1,663,652	Cigarette Extinguishing Device	11/11/1967

Country	Number	Title	Date
Germany	1,959,684	Self-Extinguishing Smoking Article	6/3/1971
Germany	2,906,417	Self-Extinguishing Filter Cigarette	2/20/1979
Germany	3,429,275	Smoking Article	8/8/1984
Great Britain	19,694	Improvements in Cigars, Cigarettes, or the Like	5/15/1913
Great Britain	22,161	Improvements in the Manufacture of Cigarettes, Cigars, and Similarly Used Tobaccos	9/25/1902
Great Britain	340,884	An Ash-Retaining Attachment for Cigarettes	1/8/1931
Great Britain	421,236	Improvements in and Relating to Cigarettes	12/17/1934
Great Britain	805,693	Improvements in or Relating to Cigarettes	2/22/1956
Great Britain	909,699	Improvements in or Relating to Tobacco, Reconstituted Tobacco, or Cigarette Paper and Products Thereof	10/31/1962
Great Britain	1,113,941	Improvements in or Relating to Cigarettes and Like Smokable Articles	5/15/1968
Great Britain	1,214,319	Improvements in or Relating to Mouthpiece Cigarettes and Like Smoke Articles	12/2/1970
Great Britain	2,175,189	Self Extinguishing Cigarette	11/26/1980
Japan	58-146 269	Self-Extinguishing Cigarette	8/31/1983
Japan	58-183,084	Self-Extinguishing Cigarette	10/26/1983
Japan	58-183,085	Self-Extinguishing Cigarette	10/26/1983
Japan	59,14,781	Cigarette with Fire Extinguisher	1/1/1984
Switzerland	142,429	Cigarette	11/17/1930
Switzerland	240,987	Extinguishing Mechanism on Manufactured Smoking Articles	6/1/1946
Switzerland	348,094	Filter for Cigarettes, Cigars, Pipes and the Like	9/15/1960
World Patent	8,604,488	Self-Extinguishing Cigarette	8/14/1986

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Technical
Study Group
Cigarette Safety
Act of 1984